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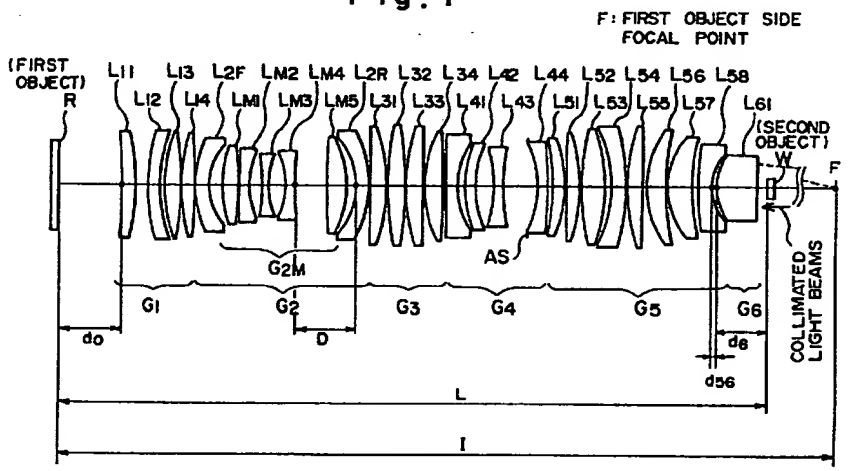
(54) Exposure apparatus

(57) A projection optical system of the present invention has a first lens group G_1 being positive, a second lens group G_2 being negative, a third lens group G_3 being positive, a fourth lens group G_4 being negative, a fifth lens group G_5 being positive, and a sixth lens group G_6 being positive in the named order from the object side, in which the second lens group G_2 comprises an intermediate lens group G_{2M} between a negative front lens L_{2F} and a negative rear lens L_{2R} and in which the intermediate lens group G_{2M} is arranged to comprise at least a first positive lens being positive, a second lens being negative, a third lens being negative, and a fourth lens being negative in the named order from the object side. The present invention involves findings of suitable focal length ranges for the first to the sixth lens groups G_1 to G_6 and an optimum range of an overall focal length of from the second negative lens to the fourth lens with respect to a focal length of the second lens group G_2.

Fig. 1



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Description

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to an exposure apparatus having a projection optical system for projecting a pattern of a first object onto a photosensitive substrate etc. as a second object, and more particularly to a projection optical system suitably applicable to projection exposure of a pattern for semiconductor or liquid crystal formed on a reticle (mask) as the first object onto the substrate (semiconductor wafer, plate, etc.) as the second object.

Related background art

As the patterns of integrated circuits become finer and finer, the resolving power required for the exposure apparatus used in printing of wafer also becomes higher and higher. In addition to the improvement in resolving power, the projection optical systems of the exposure apparatus are required to decrease image stress.

Here, the image stress includes those due to bowing etc. of the printed wafer on the image side of projection optical system and those due to bowing etc. of the reticle with circuit pattern etc. written therein, on the object side of projection optical system, as well as distortion caused by the projection optical system.

With a recent further progress of fineness tendency of transfer patterns, demands to decrease the image stress are also becoming harder.

Then, in order to decrease effects of the wafer bowing on the image stress, the conventional technology has employed the so-called image-side telecentric optical system that located the exit pupil position at a farther point on the image side of projection optical system.

On the other hand, the image stress due to the bowing of reticle can also be reduced by employing a so-called object-side telecentric optical system that locates the entrance pupil position of projection optical system at a farther point from the object plane, and there are suggestions to locate the entrance pupil position of projection optical system at a relatively far position from the object plane as described. Examples of those suggestions are described for example in Japanese Laid-open Patent Applications No. 63-118115 and No. 5-173065 and U.S.Patent No.5,260,832.

SUMMARY OF THE INVENTION

An object of the invention is to provide an exposure apparatus having a high-performance projection optical system which can correct the aberrations, particularly the distortion, very well even in the bitelecentric arrangement while keeping a relatively wide exposure area and a large numerical aperture.

To achieve the above object, the present invention involves an exposure apparatus having a high-performance projection optical system comprising a stage allowing a photosensitive substrate (for example, a semiconductor wafer coated with a photosensitive material such as a photoresist) to be held on a main surface thereof, an illumination optical system having a light source for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern on a mask onto the substrate, and a projecting optical system for projecting an image of the mask, on the substrate surface. The above projecting optical system having for projecting an image of a first object (for example, a mask with a pattern such as an integrated circuit) onto a second object (for example, a photosensitive substrate).

As shown in Fig. 1, the projection optical system has a first lens group G_1 with positive refracting power, a second lens group G_2 with negative refracting power, a third lens group G_3 with positive refracting power, a fourth lens group G_4 with negative refracting power, a fifth lens group G_5 with positive refracting power, and a sixth lens group G_6 with positive refracting power in the named order from the side of the first object R, and the second lens group G_2 further comprises a front lens L_{2F} placed as closest to the first object R and having negative refracting power with a concave surface to the second object W, a rear lens L_{2R} placed as closest to the second object and having negative refracting power with a concave surface to the first object R, and an intermediate lens group G_{2M} placed between the front lens L_{2F} in the second lens group G_2 and the rear lens L_{2R} in the second lens group G_2. The intermediate lens group G_{2M} has a first lens L_{M1} with positive refracting power, a second lens L_{M2} with negative refracting power, a third lens L_{M3} with negative refracting power, and a fourth lens L_{M4} with negative refracting power in the named order from the side of the first object R.

First, the first lens group G_1 with positive refracting power contributes mainly to a correction of distortion while maintaining telecentricity, and specifically, the first lens group G_1 is arranged to generate a positive distortion to correct in a good balance negative distortions caused by the plurality of lens groups located on the second object side after the first lens group G_1. The second lens group G_2 with negative refracting power and the fourth lens group G_4 with negative refracting power contribute mainly to a correction of Petzval sum to make the image plane flat. The two lens groups of the second lens group G_2 with negative refracting power and the third lens group G_3 with positive refracting power form

an inverse telescopic system to contribute to guarantee of back focus (a distance from an optical surface such as a lens surface closest to the second object W in the projection optical system to the second object W) in the projection optical system. The fifth lens group G_5 with positive refracting power and the sixth lens group G_6 similarly with positive refracting power contribute mainly to suppressing generation of distortion and suppressing generation particularly of spherical aberration as much as possible in order to fully support high NA structure on the second object side.

Based on the above structure, the front lens L_{2F} placed as closest to the first object R in the second lens group G_2 and having the negative refracting power with a concave surface to the second object W contributes to corrections of curvature of field and coma, and the rear lens L_{2R} placed as closest to the second object W in the second lens group G_2 and having the negative refracting power with a concave surface to the first object R to corrections of curvature of field, coma, and astigmatism. In the intermediate lens group G_{2M} placed between the front lens L_{2F} and the rear lens L_{2R}, the first lens L_{M1} with positive refracting power contributes to a correction of negative distortions caused by the second to fourth lenses L_{M2}-L_{M4} with negative refracting power greatly contributing to the correction of curvature of field.

In particular, in the above projecting optical system, the following conditions (1) to (5) are satisfied when a focal length of the first lens group G_1 is f_1, a focal length of the second lens group G_2 is f_2, a focal length of the third lens group G_3 is f_3, a focal length of the fourth lens group G_4 is f_4, a focal length of the fifth lens group G_5 is f_5, a focal length of the sixth lens group G_6 is f_6, an overall focal length of the second to the fourth lenses L_{M2}-L_{M4} in the intermediate lens group G_{2M} in the second lens group G_2 is f_n, and a distance from the first object R to the second object W is L:

$$0.1 < f_1/f_3 < 17 \quad (1)$$

$$0.1 < f_2/f_4 < 14 \quad (2)$$

$$0.01 < f_5/L < 0.9 \quad (3)$$

$$0.02 < f_6/L < 1.6 \quad (4)$$

$$0.01 < f_n/f_2 < 2.0. \quad (5)$$

The condition (1) defines an optimum ratio between the focal length f_1 of the first lens group G_1 with positive refracting power and the focal length f_3 of the third lens group $G_3$with positive refracting power, which is an optimum refracting power (power) balance between the first lens group G_1 and the third lens group G_3. This condition (1) is mainly for correcting the distortion in a good balance. Below the lower limit of this condition (1) a large negative distortion is produced because the refracting power of the third lens group G_3 becomes relatively weak to the refracting power of the first lens group G_1. Above the upper limit of the condition (1) a large negative distortion is produced because the refracting power of the first lens group G_1 becomes relatively weak to the refracting power of the third lens group G_3.

The condition (2) defines an optimum ratio between the focal length f_2 of the second lens group G_2 with negative refracting power and the focal length f_4 of the fourth lens group G_4 with negative refracting power, which is an optimum refracting power (power) balance between the second lens group G_2 and the fourth lens group G_4. This condition (2) is mainly for keeping the Petzval sum small so as to correct the curvature of field well while securing a wide exposure field. Below the lower limit of the condition (2), a large positive Petzval sum appears because the refracting power of the fourth lens group G_4 becomes relatively weak to the refracting power of the second lens group G_2. Above the upper limit of the condition (2) a large positive Petzval sum appears because the refracting power of the second lens group G_2 becomes relatively weak to the refracting power of the fourth lens group G_4. In order to correct the Petzval sum in a better balance under a wide exposure field by making the refracting power of the fourth lens group G_4 strong relative to the refracting power of the second lens group G_2, the lower limit of the above condition (2) is preferably set to 0.8, i.e., $0.8 < f_2/f_4$.

The condition (3) defines an optimum ratio between the focal length f_5 of the fifth lens group G_5 with positive refracting power and the distance (object-image distance) L from the first object R (reticle etc.) and the second object W (wafer etc.). This condition (3) is for correcting the spherical aberration, distortion, and Petzval sum in a good balance while keeping a large numerical aperture. Below the lower limit of this condition (3) the refracting power of the fifth lens group G_5 is too strong, so that this fifth lens group G_5 generates not only a negative distortion but also a great negative spherical aberration. Above the upper limit of this condition (3) the refracting power of the fifth lens group G_5 is too weak, so that the refracting power of the fourth lens group G_4 with negative refracting power inevitably also becomes weak therewith, thereby resulting in failing to correct the Petzval sum well.

The condition (4) defines an optimum ratio between the focal length f_6 of the sixth lens group G_6 with positive refracting power and the distance (object-image distance) L from the first object R (reticle etc.) to the second object W (wafer etc.). This condition (4) is for suppressing generation of higher-order spherical aberrations and negative distortion while keeping a large numerical aperture. Below the lower limit of this condition (4) the sixth lens group G_6 itself produces a large negative distortion; above the upper limit of this condition (4) higher-order spherical aberrations appear.

The condition (5) defines an optimum ratio between the overall focal length f_n of the second lens L_{M2} with negative refracting power to the fourth lens L_{M4} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 and the focal length f_2 of the second lens group G_2. It should be noted that the overall focal length f_n, stated herein, of the second lens L_{M2} with negative refracting power to the fourth lens L_{M4} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 means not only an overall focal length of three lenses, i.e. the second lens L_{M2} to the fourth lens L_{M4}, but also an overall focal length of three or more lenses between the second lens L_{M2} and the fourth lens L_{M4} where there are a plurality of lenses between the second lens and the fourth lens.

This condition (5) is for keeping the Petzval sum small while suppressing generation of distortion. Below the lower limit of this condition (5), a great negative distortion appears because the overall refracting power becomes too strong, of the negative sublens group including at least three negative lenses of from the second negative lens L_{M2} to the fourth negative lens L_{M4} in the intermediate lens group G_{2M} in the second lens group G_2. In order to sufficiently correct the distortion and coma, the lower limit of the above condition (5) is preferably set to 0.1, i.e., $0.1 < f_n/f_2$.

Above the upper limit of this condition (5) a great positive Petzval sum results because the refracting power of the negative sublens group including at least three negative lenses of from the second negative lens L_{M2} to the fourth negative lens L_{M4} in the intermediate lens group G_{2M} in the second lens group G_2 becomes too weak. In addition, the refracting power of the third lens group G_3 also becomes weak. Thus, it becomes difficult to construct the projection optical system in a compact arrangement. In order to achieve a sufficiently compact design while well correcting the Petzval sum, the upper limit of the above condition (5) is preferably set to 1.3, i.e., $f_n/f_2 < 1.3$.

Further, the following condition (6) is preferably satisfied when the axial distance from the first object R to the first-object-side focal point F of the entire projection optical system is l and the distance from the first object R to the second object W is L.

$$1.0 < l/L \tag{6}$$

The condition (6) defines an optimum ratio between the axial distance l from the first object R to the first-object-side focal point F of the entire projection optical system and the distance (object-image distance) L from the first object R (reticle etc.) to the second object W (wafer etc.). Here, the first-object-side focal point F of the entire projection optical system means an intersecting point of outgoing light from the projection optical system with the optical axis after collimated light beams are let to enter the projection optical system on the second object side in the paraxial region with respect to the optical axis of the projection optical system and when the light beams in the paraxial region are outgoing from the projection optical system.

Below the lower limit of this condition (6) the first-object-side telecentricity of the projection optical system will become considerably destroyed, so that changes of magnification and distortion due to an axial deviation of the first object R will become large. As a result, it becomes difficult to faithfully project an image of the first object R at a desired magnification onto the second object W. In order to fully suppress the changes of magnification and distortion due to the axial deviation of the first object R, the lower limit of the above condition (6) is preferably set to 1.7, i.e., $1.7 < l/L$. Further, in order to correct a spherical aberration and a distortion of the pupil both in a good balance while maintaining the compact design of the projection optical system, the upper limit of the above condition (6) is preferably set to 6.8, i.e., $l/L < 6.8$.

Also, it is more preferable that the following condition (7) be satisfied when the focal length of the third lens L_{M3} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 is f_{23} and the focal length of the fourth lens L_{M4} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 is f_{24}.

$$0.07 < f_{24}/f_{23} < 7. \tag{7}$$

Below the lower limit of the condition (7) the refracting power of the fourth negative lens L_{M4} becomes strong relative to the refracting power of the third negative lens L_{M3}, so that the fourth negative lens L_{M4} generates a large coma and a large negative distortion. In order to correct the coma better while correcting the negative distortion, the lower limit of the above condition (7) is preferably set to 0.14, i.e., $0.14 < f_{24}/f_{23}$. Above the upper limit of this condition (7) the refracting power of the third negative lens L_{M3} becomes relatively strong relative to the refracting power of the fourth negative lens L_{M4}, so that the third negative lens L_{M3} generates a large coma and a large negative distortion. In order to correct the negative distortion better while correcting the coma, the upper limit of the above condition (7) is preferably set to 3.5, i.e., $f_{24}/f_{23} < 3.5$.

Further, it is more preferable that the following condition (8) be satisfied when the focal length of the second lens L_{M2} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 is f_{22} and the focal length of the third lens L_{M3} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 is f_{23}.

$$0.1 < f_{22}/f_{23} < 10 \tag{8}$$

Below the lower limit of the condition (8) the refracting power of the second negative lens L_{M2} becomes strong relative to the refracting power of the third negative lens L_{M3}, so that the second negative lens L_{M2} generates a large coma and a large negative distortion. In order to correct the negative distortion in a better balance, the lower limit of the above condition (8) is preferably set to 0.2, i.e., $0.2 < f_{22}/f_{23}$. Above the upper limit of this condition (8) the refracting power of the third negative lens L_{M3} becomes strong relative to the refracting power of the second negative lens L_{M2}, so that the third negative lens L_{M3} generates a large coma and a large negative distortion. In order to correct the negative distortion in a better balance while well correcting the coma, the upper limit of the above condition (8) is preferably set to 5, i.e., $f_{22}/f_{23} < 5$.

Also, it is more desirable that the following condition (9) be satisfied when the axial distance from the second-object-side lens surface of the fourth lens L_{M4} with negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 to the first-object-side lens surface of the rear lens L_{2R} in the second lens group G_2 is D and the distance from the first object R to the second object W is L:

$$0.05 < D/L < 0.4. \tag{9}$$

Below the lower limit of the condition (9) it becomes difficult not only to secure a sufficient back focus on the second object side but also to correct the Petzval sum well. Above the upper limit of the condition (9) a large coma and a large negative distortion appear. Further, for example, in order to avoid mechanical interference between a reticle stage for holding the reticle as the first object R and the first lens group G_1, there are cases that it is preferable to secure a sufficient space between the first object R and the first lens group G_1, but there is a problem that to secure the sufficient space will become difficult above the upper limit of the condition (9).

Also, the fourth lens group G_4 preferably satisfies the following condition when the focal length of the fourth lens group G_4 is f_4 and the distance from the first object R to the second object W is L.

$$-0.098 < f_4/L < -0.005 \tag{10}$$

Below the lower limit of the condition (10) the correction of spherical aberration becomes difficult, which is not preferable. Also, above the upper limit of the condition (10), the coma appears, which is not preferable. In order to well correct the spherical aberration and Petzval sum, the lower limit of the condition (10) is preferably set to -0.078, i.e., $-0.078 < f_4/L$, and further, in order to suppress generation of coma, the upper limit of the condition (10) is preferably set to -0.047, i.e., $f_4/L < -0.047$.

Further, the second lens group G_2 preferably satisfies the following condition when the focal length of the second lens group G_2 is f_2 and the distance from the first object R to the second object W is L.

$$-0.8 < f_2/L < -0.050 \tag{11}$$

Here, below the lower limit of the condition (11), a positive Petzval sum results, which is not preferable. Also, above the upper limit of the condition (11), a negative distortion appears, which is not preferable. In order to better correct the Petzval sum, the lower limit of the condition (11) is preferably set to -0.16, i.e., $-0.16 < f_2/L$, and in order to better correct the negative distortion and coma, the upper limit of the condition (11) is preferably set to -0.0710, i.e., $f_2/L < -0.0710$.

In order to well correct mainly the third-order spherical aberration, it is more desirable that the fifth lens group G_5 with positive refracting power have the negative meniscus lens L_{54}, and the positive lens L_{53} placed adjacent to the concave surface of the negative meniscus lens L_{54} and having a convex surface opposed to the concave surface of the negative meniscus lens L_{54} and that the following condition (12) be satisfied when the radius of curvature of the concave surface in the negative meniscus lens L_{54} in the fifth lens group G_5 is r_{5n} and the radius of curvature of the convex surface opposed to the concave surface of the negative meniscus lens L_{54} in the positive lens L_{53} set adjacent to the concave surface of the negative meniscus lens L_{54} in the fifth lens group G_5 is r_{5p}.

$$0 < (r_{5p} - r_{5n})/(r_{5p} + r_{5n}) < 1 \tag{12}$$

Below the lower limit of the condition (12), correction of the third-order spherical aberration becomes insufficient; conversely, above the upper limit of the condition (12), the correction of the third-order spherical aberration becomes excessive, which is not preferable. Here, in order to correct the third-order spherical aberration better, the lower limit of the condition (12) is more preferably set to 0.01, i.e., $0.01 < (r_{5p} - r_{5n})/(r_{5p} + r_{5n})$ and the upper limit of the condition (12) is more preferably set to 0.7, i.e., $(r_{5p} - r_{5n})/(r_{5p} + r_{5n}) < 0.7$.

Here, it is preferred that the negative meniscus lens and the positive lens adjacent to the concave surface of the negative meniscus lens be set between the at least one positive lens in the fifth lens group G_5 and the at least one positive lens in the fifth lens group G_5. For example, a set of the megative meniscus lens L_{54} and the positive lens L_{53}

is placed between the positive lenses L_{52} and L_{55}. This arrangement can suppress generation of the higher-order spherical aberrations which tend to appear with an increase in NA.

Also, it is more desirable that the fourth lens group G_4 with negative refracting power have the front lens L_{41} placed as closest to the first object R and having the negative refracting power with a concave surface to the second object W, the rear lens L_{44} placed as closest to the second object W and having the negative refracting power with a concave surface to the first object R, and at least one negative lens placed between the front lens L_{41}in the fourth lens group G_4 and the rear lens L_{41} in the fourth lens group G_4 and that the following condition (13) be satisfied when a radius of curvature on the first object side in the rear lens L_{44} placed as closest to the second object W in the fourth lens group G_4 is r_{4F} and a radius of curvature on the second object side in the rear lens L_{44} placed as closest to the second object W in the fourth lens group G_4 is r_{4R}.

$$-1.00 \leq (r_{4F} - r_{4R})/(r_{4F} + r_{4R}) < 0 \quad (13)$$

Below the lower limit of the condition (13), the rear negative lens L_{44} located closest to the second object W in the fourth lens group G_4 becomes of a double-concave shape which generates higher-order spherical aberrations; conversely, above the upper limit of the condition (13), the rear negative lens L_{44} located closest to the second object W in the fourth lens group G_4 will have positive refracting power, which will make the correction of Petzval sum more difficult.

Further, it is desirable that the fifth lens group G_5 have the negative lens L_{58} with a concave surface to the second object W, on the most second object side thereof. This enables the negative lens L_{58} located closest to the second object W in the fifth lens group G_5 to generate a positive distortion and a negative Petzval sum, which can cancel a negative distortion and a positive Petzval sum generated by the positive lenses in the fifth lens group G_5.

In this case, in order to suppress the negative distortion without generating the higher-order spherical aberrations in the lens L_{61} located closest to the first object R in the sixth lens group G_6, it is desirable that the lens surface closest to the first object R have a shape with a convex surface to the first object R and that the following condition be satisfied when a radius of curvature on the second object side, of the negative lens L_{58} placed as closest to the second object W in the fifth lens group G_5 is r_{5R} and a radius of curvature on the first object side, of the lens L_{61} placed as closest to the first object R in the sixth lens group G_6 is r_{6F}.

$$-0.90 < (r_{5R} - r_{6F})/(r_{5R} + r_{6F}) < -0.001 \quad (14)$$

This condition (14) defines an optimum shape of a gas lens formed between the fifth lens group G_5 and the sixth lens group G_6. Below the lower limit of this condition (14) a curvature of the second-object-side concave surface of the negative lens L_{58} located closest to the second object W in the fifth lens group G_5 becomes too strong, thereby generating higher-order comas. Above the upper limit of this condition (14) refracting power of the gas lens itself formed between the fifth lens group G_5 and the sixth lens group G_6 becomes weak, so that a quantity of the positive distortion generated by this gas lens becomes small, which makes it difficult to well correct a negative distortion generated by the positive lenses in the fifth lens group G_5. In order to fully suppress the generation of higher-order comas, the lower limit of the above condition (14) is preferably set to -0.30, i.e., $-0.30 < (r_{5R} - r_{6F})/(r_{5R} + r_{6F})$.

Also, it is further preferable that the following condition be satisfied when a lens group separation between the fifth lens group G_5 and the sixth lens group G_6 is d_{56} and the distance from the first object R to the second object W is L.

$$d_{56}/L < 0.017 \quad (15)$$

Above the upper limit of this condition (15), the lens group separation between the fifth lens group G_5 and the sixth lens group G_6 becomes too large, so that a quantity of the positive distortion generated becomes small. As a result, it becomes difficult to correct the negative distortion generated by the positive lens in the fifth lens group G_5 in a good balance.

Also, it is more preferable that the following condition be satisfied when a radius of curvature of the lens surface closest to the first object R in the sixth lens group G_6 is r_{6F} and an axial distance from the lens surface closest to the first object R in the sixth lens group G_6 to the second object W is d_6.

$$0.50 < d_6/r_{6F} < 1.50 \quad (16)$$

Below the lower limit of this condition (16), the positive refracting power of the lens surface closest to the first object R in the sixth lens group G_6 becomes too strong, so that a large negative distortion and a large coma are generated. Above the upper limit of this condition (16), the positive refracting power of the lens surface closest to the first object R in the sixth lens group G_{61} becomes too weak, thus generating a large coma. In order to further suppress the generation of coma, the lower limit of the condition (16) is preferably set to 0.84, i.e., $0.84 < d_6/r_{6F}$.

It is desirable that the following condition (17) be satisfied when the radius of curvature on the first object side in the negative lens L_{58} located closest to the second object W in the fifth lens group G_5 is r_{5F} and the radius of curvature on the second object side in the negative lens L_{58} located closest to the second object W in the fifth lens group G_5 is r_{5R}.

$$0.30 < (r_{5F} - r_{5R})/(r_{5F} + r_{5R}) < 1.28 \quad (17)$$

Below the lower limit of this condition (17), it becomes difficult to correct both the Petzval sum and the coma; above the upper limit of this condition (17), large higher-order comas appear, which is not preferable. In order to further prevent the generation of higher-order comas, the upper limit of the condition (17) is preferably set to 0.93, i.e., $(r_{5F} - r_{5R})/(r_{5F} + r_{5R}) < 0.93$.

Further, it is desirable that the second-object-side lens surface of the first lens L_{M1} with positive refracting power in the intermediate lens group G_{2M} in the second lens group G_2 be of a lens shape with a convex surface to the second object W, and in this case, it is more preferable that the following condition (18) be satisfied when the refracting power on the second-object-side lens surface of the first positive lens L_{M1} in the intermediate lens group G_{2M} in the second lens group G_2 is Φ_{21} and the distance from the first object R to the second object W is L.

$$0.54 < 1/(\Phi_{21} \cdot L) < 10 \quad (18)$$

The refracting power of the second-object-side lens surface, stated herein, of the first lens L_{M1} with positive refracting power in the intermediate lens group G_{2M} is given by the following formula when a refractive index of a medium for the first lens L_{M1} is n_1, a refracting index of a medium in contact with the second-object-side lens surface of the first lens L_{M1} is n_2, and a radius of curvature of the second-object-side lens surface of the first lens is r_{21}.

$$\Phi_{21} = (n_2 - n_1)/r_{21}$$

Below the lower limit of the condition (18), higher-order distortions appear; conversely, above the upper limit of the condition (18), it becomes necessary to correct the distortion more excessively by the first lens group G_1, which generates the spherical aberration of the pupil, thus being not preferable.

Further, it is more preferable that the following condition (19) be satisfied when the focal length of the first lens L_{M1} with positive refracting power in the intermediate lens group G_{2M} in the second lens group G_2 is f_{21} and the distance from the first object R to the second object W is L.

$$0.230 < f_{21}/L < 0.40 \quad (19)$$

Below the lower limit of the condition (19), a positive distortion appears; above the upper limit of the condition (19), a negative distortion appears, thus not preferable.

Also, the front lens L_{2F} and rear lens L_{2R} in the second lens group G_2 preferably satisfy the following condition when the focal length of the front lens L_{2F} placed as closest to the first object R in the second lens group G_2 and having the negative refracting power with a concave surface to the second object W is f_{2F} and the focal length of the rear lens L_{2R} placed as closest to the second object W in the second lens group G_2 and having the negative refracting power with a concave surface to the first object R is f_{2R}.

$$0 \leq f_{2F}/f_{2R} < 18 \quad (20)$$

The condition (20) defines an optimum ratio between the focal length f_{2R} of the rear lens L_{2R} in the second lens group G_2 and the focal length f_{2F} of the front lens L_{2F} in the second lens group G_2. Below the lower limit and above the upper limit of this condition (20), a balance is destroyed for refracting power of the first lens group G_1 or the third lens group G_3, which makes it difficult to correct the distortion well or to correct the Petzval sum and the astigmatism simultaneously well.

The following specific arrangements are desirable to provide the above respective lens groups with sufficient aberration control functions.

First, in order to provide the first lens group G_1 with a function to suppress generation of higher-order distortions and spherical aberration of the pupil, the first lens group G_1 preferably has at least two positive lenses; in order to provide the third lens group G_3 with a function to suppress degradation of the spherical aberration and the Petzval sum, the third lens group G_3 preferably has at least three positive lenses; further, in order to provide the fourth lens group G_4 with a function to suppress the generation of coma while correcting the Petzval sum, the fourth lens group G_4 preferably has at least three negative lenses. Further, in order to provide the fifth lens group G_5 with a function to suppress generation of the negative distortion and the spherical aberration, the fifth lens group G_5 preferably has at least five positive lenses; further, in order to provide the fifth lens group G_5 with a function to correct the negative distortion and the Petzval sum,

the fifth lens group G_5 preferably has at least one negative lens. Also, in order to provide the sixth lens group G_6 with a function to converge light on the second object W without generating a large spherical aberration, the sixth lens group G_6 preferably has at least one positive lens.

In addition, in order to correct the Petzval sum better, the intermediate lens group G_{2M} in the second lens group G_2 preferably has negative refracting power.

In order to provide the sixth lens group G_6 with a function to further suppress the generation of the negative distortion, the sixth lens group G_6 is preferably constructed of three or less lenses having at least one surface satisfying the following condition (21).

$$1/|\Phi L| < 20 \qquad (21)$$

where Φ: refracting power of the lens surface;

L: object-image distance from the first object R to the second object W.

The refracting power of the lens surface stated herein is given by the following formula when the radius of curvature of the lens surface is r, a refracting index of a medium on the first object side, of the lens surface is n_1, and a medium on the second object side, of the lens surface is n_2.

$$\Phi = (n_2 - n_1)/r$$

Here, if there are four or more lenses having the lens surface satisfying this condition (21), the number of lens surfaces with some curvature, located near the second object W, becomes increased, which generates the distortion, thus not preferable.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art form this detailed description.

BRIEF DESCRIPRION OF THE DRAWINGS

Fig. 1 is adrwing to show parameters defined in embodiments of the present invention.
Fig. 2 is a drawing to show schematic structure of an exposure apparatus according to the present invention.
Fig. 3 is a lens makeup diagram in the first embodiment according to the present invention.
Fig. 4 is a lens makeup diagram in the second embodiment according to the present invention.
Fig. 5 is a lens makeup diagram in the third embodiment according to the present invention.
Fig. 6 is a lens makeup diagram in the fourth embodiment according to the present invention.
Fig. 7 is a lens makeup diagram in the fifth embodiment according to the present invention.
Fig. 8 is a lens makeup diagram in the sixth embodiment according to the present invention.
Fig. 9 is various aberration diagrams in the first embodiment according to the present invention.
Fig. 10 is various aberration diagrams in the second embodiment according to the present invention.
Fig. 11 is various aberration diagrams in the third embodiment according to the present invention.
Fig. 12 is various aberration diagrams in the fourth embodiment according to the present invention.
Fig. 13 is various aberration diagrams in the fifth embodiment according to the present invention.
Fig. 14 is various aberration diagrams in the sixth embodiment according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments according to the present invention will be described in detail in the following. An exposure apparatus of the invention comprises a projection optical system as showing in Fig. 2.

First, briefly describing Fig. 2, a reticle R (first object) is placed as a mask on which a predetermined circuit pattern 101 is formed, on the object plane of a projection optical system PL and a wafer W (second object) as a photosensitive substrate on the image plane of the projection optical system PL, as shown. The reticle R is held on a reticle stage RS while the wafer W on a wafer stage WS. The photosensitive substrate comprises the wafer W and a photosensitive layer 100 made of a material as a photoresistor. Further, an illumination optical system IS, which has a light source 102 for emitting exposure light of a predetermined wavelength, for uniformly illuminating the reticle R is set above the reticle R.

In the above arrangement, light supplied from the illumination optical system IS illuminates the reticle R to form an image of a light source in the illumination optical apparatus IS at the pupil position (or a position of aperture stop AS) of

the projection optical system PL, thus achieving the so-called Köhler illumination. Then, through the projection optical system PL, a pattern image of the thus Köhler-illuminated reticle R is projected (or transferred) onto the wafer W through the photosensitive layer 100 by the projection optical system PL. The techniques relating to an exposure apparatus of the present invention are described for example in U.S.Patents No. 5,194,893, No. 5,097,291 and No. 5,245,384 and U.S.Patent Applications No. 299,305, No. 255,927 and No. 226,327.

The present embodiment shows an example of projection optical system where the light source 102 inside the illumination optical system IS is an excimer laser supplying light with exposure wavelength λ of 248.4 nm, and Fig. 3 to Fig. 8 are lens makeup diagrams of projection optical systems in the first to sixth embodiments according to the present invention.

As shown in Fig. 3 to Fig. 8, a projection optical system in each embodiment has a first lens group G_1 with positive refracting power, a second lens group G_2 with negative refracting power, a third lens group G_3 with positive refracting power, a fourth lens group G_4 with negative refracting power, a fifth lens group G_5 with positive refracting power, and a sixth lens group G_6 with positive refracting power in the named order from the side of reticle R as the first object, which is approximately telecentric on the object side (or on the reticle R side) and on the image side (or on the wafer W side) and which has a reduction magnification.

The projection optical systems of the respective embodiments shown in Fig. 3 to Fig. 8 are arranged so that the object-image distance (a distance from the object plane to the image plane or a distance from the reticle R to the wafer W) L is 1200, the image-side numerical aperture NA is 0.55, the projection magnification B is 5:1, and the diameter of the exposure area on the wafer W is 31.2. In the explanation of embodiments of the present invention, the image plane means a main surface of the wafer W, and the object plane means a surface of the reticle R.

Specifically describing the lens makeup of the first embodiment, as shown in Fig. 3, first, the first lens group G_1 has a positive lens L_{11} with a convex surface to the image (positive meniscus lens), a negative lens L_{12} of a meniscus shape with a convex surface to the object, and two positive lenses (L_{13}, L_{14}) of a double-convex shape in the named order from the object side.

Next, the second lens group G_2 is composed of a negative meniscus lens (front lens) L_{2F} placed as closest to the object with a concave surface to the image, a negative meniscus lens (rear lens) L_{2R} placed closest to the image with a concave surface to the object, and an intermediate lens group G_{2M} placed between the negative meniscus lens L_{2F} located closest to the object in the second lens group G_2 and the negative meniscus lens L_{2R} located closest to the image in the second lens group G_2, and having negative refracting power.

The intermediate lens group G_{2M} is composed of a positive lens (first lens) L_{M1} of a double-convex shape, a negative lens (second lens) L_{M2} with a surface of a greater curvature to the image, a negative lens (third lens) L_{M3} of a double-concave shape, a negative lens (fourth lens) L_{M4} with a surface of a greater curvature to the object, and a positive lens (fifth lens) L_{M5} with a surface of a greater curvature to the image in the named order from the object side.

Further, the third lens group G_3 is composed of a positive lens (positive meniscus lens) L_{31} with a surface of a greater curvature to the image, a positive lens L_{32} of a double-convex shape, a positive lens (a positive lens of a double-convex shape) L_{33} with a convex surface to the object, and a positive lens L_{34} with a surface of a greater curvature to the object, and the fourth lens group G_4 is composed of a negative lens (negative meniscus lens) L_{41} with a concave surface to the image, a negative meniscus lens L_{42} with a concave surface to the image, a negative lens L_{43} of a double concave surface, and a negative meniscus lens L_{44} with a concave surface to the object.

Here, an aperture stop AS is set in an optical path between the image-side concave surface of the negative lens L_{41} in the fourth lens group G_4 and the object-side concave surface of the negative meniscus lens L_{44}.

The fifth lens group G_5 is composed of a positive meniscus lens L_{51} with a convex surface to the image, a positive lens with a surface of a greater curvature to the image (a positive lens of a double-convex shape) L_{52}, a positive lens L_{53} of a double-convex shape, a negative meniscus lens L_{54} with a concave surface to the object, a positive lens L_{55} with a surface of a greater curvature to the object, a positive meniscus lens L_{56} with a convex surface to the object, a positive lens with a surface of a greater curvature to the object (positive meniscus lens) L_{57}, and a negative lens with a concave surface to the image (negative meniscus lens) L_{58}, and the sixth lens group G_6 is composed only of a thick-wall positive lens L_{61} with a convex surface to the object.

Here, because the first lens group G_1 in the first embodiment is so arranged that the image-side lens surface of the negative lens L_{12} of the meniscus shape with its convex surface to the object and the object-side lens surface of the positive lens L_{13} of double-convex shape have nearly equal curvatures and are arranged as relatively close to each other, these two lens surfaces correct the higher-order distortions.

In the present embodiment, because the front lens L_{2F} with negative refracting power, placed closest to the object in the second lens group G_2, is of the meniscus shape with a concave surface to the image, the generation of coma can be reduced; because the first lens L_{M1} with positive refracting power in the second lens group G_{2M} is of the double-convex shape with a convex surface to the image and another convex surface to the object, the generation of spherical aberration of the pupil can be suppressed. Further, because the fifth lens L_{M5} with positive refracting power in the intermediate lens group G_{2M} has the convex surface opposed to the concave surface of the rear lens L_{2R} with negative refracting power placed on the image side thereof, the astigmatism can be corrected.

Since the fourth lens group G_4 is so arranged that the negative lens L_{41} with its concave surface to the image is placed on the object side of the negative lens (negative lens of double-concave shape) L_{43} and that the negative meniscus lens L_{44} with its concave surface to the object is placed on the image side of the negative lens (negative lens of double-concave shape) L_{43}, the Petzval sum can be corrected while suppressing the generation of coma.

The present embodiment is so arranged that the aperture stop AS is placed between the image-side concave surface of the negative lens L_{41} and the object-side concave surface of the negative meniscus lens L_{44} in the fourth lens group G_4 whereby the lens groups of from the third lens group G_3 to the sixth lens group G_6 can be arranged on either side of the aperture stop AS with some reduction magnification and without destroying the symmetry so much, which can suppress generation of asymmetric aberrations, specifically generation of coma or distortion.

Since the positive lens L_{53} in the fifth lens group G_5 is of the double-convex shape where its convex surface is opposed to the negative meniscus lens L_{54} and the other lens surface opposite to the negative meniscus lens L_{54} is also a convex surface, the generation of higher-order spherical aberrations with an increase in NA can be suppressed.

The specific lens makeup of the projection optical system in the second embodiment as shown in Fig. 4 is similar to that of the first embodiment shown in Fig. 3 and described above but different in that the fourth lens group G_4 is composed of a negative lens with a concave surface to the image (negative lens of a plano-concave shape) L_{41}, a negative meniscus lens L_{42} with a concave surface to the image, a negative lens L_{43} of a double-concave shape, and a negative meniscus lens L_{44} with a concave surface to the object and in that the sixth lens group G_6 is composed of a positive lens with a convex surface to the object (positive meniscus lens) L_{61}, and a positive lens with a convex surface to the object (positive meniscus lens) L_{62}.

Also in the second embodiment, the image-side lens surface of the negative meniscus lens L_{12} with its convex surface to the object and the object-side lens surface of the positive lens L_{13} of double-convex shape correct the higher-order distortions, similarly as in the above first embodiment. Further, the sixth lens group G_6 is preferably composed of a less number of constituent lenses in order to suppress a distortion generated by the sixth lens group G_6, but if it is difficult to produce a thick lens the sixth lens group G_6 may be composed of two lenses as in the present embodiment. As for the other lens groups (the second lens group G_1 to the fifth lens group G_5) in the second embodiment, the same functions as in the first embodiment are achieved thereby.

The specific lens makeup of the projection optical system of the third embodiment as shown in Fig. 5 is similar to that of the first embodiment shown in Fig. 3 and described previously, but different in that the first lens group G_1 is composed of a positive lens with a convex surface to the image (positive lens of double-convex shape) L_{11}, a positive lens with a convex surface to the image (positive lens of double-convex shape) L_{12}, a negative meniscus lens L_{13} with a concave surface to the object, and a positive lens L_{14} of double-convex shape in the named order from the object side and in that the third lens group G_3 is composed of a positive lens with a surface of a greater curvature to the image (positive meniscus lens) L_{31}, a positive lens L_{32} of double-convex shape, a positive lens with a surface of a greater curvature to the object (positive lens of double-convex shape) L_{33}, and a positive lens with a convex surface to the object (positive meniscus lens) L_{34}.

In the third embodiment, the image-side lens surface of the positive lens L_{12} with its convex surface to the image and the object-side lens surface of the negative meniscus lens L_{13} with its concave surface to the object correct the higher-order distortions. As for the other lens groups (the second lens group G_2, and the fourth lens group G_4 to the sixth lens group G_6) in the third embodiment, the same functions as in the first embodiment are achieved thereby.

The specific lens makeup of the projection optical system of the fourth embodiment as shown in Fig. 6 is similar to that of the third embodiment shown in Fig. 5 and described above, but different in that the third lens group G_3 is composed of a positive lens with a surface of a greater curvature to the image side (positive meniscus lens) L_{31}, a positive lens L_{32} of double-convex shape, a positive lens with a convex surface to the object (positive lens of double-convex shape) L_{33}, and a positive lens with a surface of a greater curvature to the object (positive lens of double-convex shape) L_{34} and in that the fourth lens group G_4 is composed of a negative lens with a concave surface to the image (negative lens of double-concave shape) L_{41}, a negative meniscus lens L_{42} with a concave surface to the image, a negative lens L_{43} of double-concave shape, and a negative meniscus lens L_{44} with a concave surface to the object. The present embodiment is also different in that the sixth lens group G_6 is composed of a positive lens with a convex surface to the object (positive meniscus lens) L_{61} and a positive lens with a convex surface to the object (positive meniscus lens) L_{62}.

The first lens group G_1 in the fourth embodiment achieves the same functions as in the third embodiment described previously, the second lens group G_2 to the fifth lens group G_5 do the same functions as in the first embodiment, and the sixth lens group G_6 does the same functions as in the second embodiment.

The specific lens makeup of the projection optical system of the fifth embodiment shown in Fig. 7 is similar to that of the first embodiment shown in Fig. 3 and described previously, but different in that the first lens group G_1 is composed of a positive lens with a convex surface to the image (positive lens of double-convex shape) L_{11}, a negative lens with a concave surface to the image (negative lens of double-concave shape) L_{12} and two positive lenses (L_{13}, L_{14}) of double-convex shape in the named order from the object side. It is also different in that the third lens group G_3 is composed of a positive lens with a surface of a greater curvature to the image (positive meniscus lens) L_{31}, a positive lens L_{32} of double-convex shape, a positive lens with a convex surface to the object (positive meniscus lens) L_{33}, and a positive

lens with a surface of a greater curvature to the object (positive lens of double-convex shape) L_{34}. It is also different from the lens makeup of the first embodiment in that the fourth lens group G_4 is composed of a negative lens with a concave surface to the image (negative lens of double-concave shape) L_{41}, a negative meniscus lens L_{42} with a concave surface to the image, a negative lens L_{43} of double-concave shape, and a negative meniscus lens L_{44} with a concave surface to the object. It is further different in that the fifth lens group G_5 is composed of a positive meniscus lens L_{51} with a convex surface to the image, a positive lens with a surface of a greater curvature to the image (positive meniscus lens) L_{52}, a positive lens L_{53} of double-convex shape, a negative meniscus lens L_{54} with a concave surface to the object, a positive lens with a surface of a greater curvature to the object (positive meniscus lens) L_{55}, a positive meniscus lens L_{56} with a convex surface to the object, a positive lens with a surface of a greater curvature to the object (positive meniscus lens) L_{57}, and a negative lens with a concave surface to the image (negative meniscus lens) L_{58}.

In the fifth embodiment the higher-order distortions are corrected by a pair of the image-side convex surface of the positive lens L_{11} and the object-side concave surface of the negative lens L_{12} and a pair of the image-side concave surface of the negative lens L_{12} and the object-side convex surface of the positive lens L_{13}. As for the other lens groups (the second to the fifth lens groups G_2 to G_5) in the fifth embodiment, the same functions as in the first embodiment are achieved thereby.

The sixth embodiment shown in Fig. 8 has the same lens makeup as that of the fifth embodiment as described above, and achieves the substantially same functions as in the fifth embodiment.

Now, Table 1 to Table 12 listed below indicate values of specifications and numerical values corresponding to the conditions in the respective embodiments according to the present invention.

In the tables, left end numerals represent lens surfaces located in the named order from the object side (reticle side), r curvature radii of lens surfaces, d lens surface separations, n refractive indices of synthetic quartz SiO_2 for the exposure wavelength λ of 248.4 nm, d0 a distance from the first object (reticle) to the lens surface (first lens surface) closest to the object (reticle) in the first lens group G1, Bf a distance from the lens surface closest to the image (wafer) in the sixth lens group G_6 to the image plane (wafer surface), B a projection magnification of the projection optical system, NA the image-side numerical aperture of the projection optical system, L the object-image distance from the object plane (reticle surface) to the image plane (wafer surface), l the axial distance from the first object (reticle) to the first-object-side focal point of the entire projection optical system (where the first-object-side focal point of the entire projection optical system means an intersecting point of exit light with the optical axis after collimated light beams in the paraxial region with respect to the optical axis of the projection optical system are let to enter the projection optical system on the second object side and when the light beams in the paraxial region are outgoing from the projection optical system), f_1 the focal length of the first lens group G_1, f_2 the focal length of the second lens group G_2, f_3 the focal length of the third lens group G_3, f_4 the focal length of the fourth lens group G_4, f_5 the focal length of the fifth lens group G_5, f_6 the focal length of the sixth lens group G_6, f_n the overall focal length of from the second lens to the fourth lens, f_{2F} the focal length of the front lens placed closest to the first object in the second lens group and having negative refracting power with its concave surface to the second object, f_{2R} the focal length of the rear lens placed closest to the second object in the second lens group and having negative refracting power with its concave surface to the first object, f_{21} the focal length of the first lens with positive refracting power in the intermediate lens group in the second lens group, f_{22} the focal length of the second lens with negative refracting power in the second lens group, f_{23} the focal length of the third lens with negative refracting power in the second lens group, f_{24} the focal length of the fourth lens with negative refracting power in the second lens group, Φ_{21} the refracting power of the second-object-side lens surface of the first lens with positive refracting power in the intermediate lens group G_{21} in the second lens group, D the axial distance from the second-object-side lens surface of the fourth lens in the intermediate lens group in the second lens group to the first-object-side lens surface of the rear lens in the second lens group, r_{5n} the curvature radius of the concave surface in the negative meniscus lens in the fifth lens group, r_{5p} the curvature radius of the convex surface opposed to the concave surface of the negative meniscus lens, in the positive lens placed adjacent to the concave surface of the negative meniscus lens in the fifth lens group, r_{4F} the first-object-side curvature radius in the rear lens placed closest to the second object in the fourth lens group, r_{4R} the second-object-side curvature radius in the rear lens placed closest to the second object in the fourth lens group, r_{5F} the first-object-side curvature radius in the second lens placed closest to the second object in the fifth lens group, r_{5R} the second-object-side curvature radius of the negative lens placed closest to the second object in the fifth lens group, r_{6F} the first-object-side curvature radius of the lens placed closest to the first object in the sixth lens group, d_{56} the lens group separation between the fifth lens group and the sixth lens group, d_6 the axial distance from the lens surface closest to the first object in the sixth lens group to the second object, and Φ the refracting power of the lens surface of the lens or lenses forming the sixth lens group.

(Table 1) First Embodiment

d0 = 105.33208

B = 1/5

NA = 0.55

Bf = 28.62263

L = 1200

	r	d	n
1	-821.91920	23.00000	1.50839
2	-391.93385	20.81278	
3	334.30413	20.00000	1.50839
4	239.01947	7.92536	
5	267.66514	28.00000	1.50839
6	-618.41676	1.04750	
7	337.90351	23.00000	1.50839
8	-1279.67000	0.97572	
9	200.03116	24.00000	1.50839
10	105.22457	22.04713	
11	219.65515	26.00000	1.50839
12	-546.12474	1.10686	
13	4788.40002	17.00000	1.50839
14	125.70412	20.76700	
15	-381.52610	12.90000	1.50839
16	134.36400	26.88549	
17	-127.38724	15.00000	1.50839

18	433.13808	52.33906	
19	1260.83000	35.00000	1.50839
20	-178.61526	14.91509	
21	-129.71674	22.80000	1.50839
22	-202.88016	2.79782	
23	-4128.12000	27.00000	1.50839
24	-299.28737	2.87255	
25	556.52963	28.00000	1.50839
26	-928.16848	2.49780	
27	367.82207	30.00000	1.50839
28	-4438.51001	1.64701	
29	220.29374	31.00000	1.50839
30	-1698.69000	3.60527	
31	4987.07001	21.00000	1.50839
32	146.02635	11.76890	
33	216.75649	17.00000	1.50839
34	161.01290	31.54706	
35	-206.90673	15.90000	1.50839
36	309.12541	56.09046	
37	-183.11187	18.00000	1.50839
38	-894.17440	6.28784	
39	-409.02115	23.00000	1.50839
40	-215.49999	1.14438	
41	3139.57999	23.00000	1.50839
42	-320.84882	2.92283	
43	445.47649	38.00000	1.50839

44	-348.37380	11.43498	
45	-229.01731	27.00000	1.50839
46	-352.88961	1.10071	
47	370.91242	25.00000	1.50839
48	-3446.41000	4.83032	
49	178.35450	32.00000	1.50839
50	471.60399	3.29194	
51	137.85195	39.90000	1.50839
52	331.09797	9.82671	
53	520.77561	23.00000	1.50839
54	80.26937	7.04896	
55	90.74309	71.00000	1.50839
56	1836.49001		

(Table 2) Values corresponding to the Conditions in the First Embodiment

(1) $f1/f3 = 1.47$

(2) $f2/f4 = 1.31$

(3) $f5/L = 0.0988$

(4) $f6/L = 0.154$

(5) $fn/f2 = 0.589$

(6) $I/L = 2.33$

(7) $f24/f23 = 0.990$

(8) $f22/f23 = 1.31$

(9) $D/L = 0.0852$

(10) $f4/L = -0.0638$

(11) $f2/L = -0.0834$

(12) $(r5p-r5n)/(r5p+r5n) = 0.207$

(13) $(r4F-r4R)/(r4F+r4R) = -0.660$

(14) $(r5R-r6F)/(r5R+r6F) = -0.0613$

(15) $d56/L = 0.00587$

(16) $d6/r6F = 1.10$

(17) $(r5F-r5R)/(r5F+r5R) = 0.733$

(18) $1/(\phi 21 \cdot L) = 0.895$

(19) $f21/L = 0.260$

(20) $f2F/f2R = 0.604$

(Table 3) Second Embodiment

d0 = 103.54346

B = 1/5

NA = 0.55

Bf = 29.06029

L = 1200

	r	d	n
1	-2191.45999	23.00000	1.50839
2	-443.19378	18.81278	
3	372.47246	20.00000	1.50839
4	259.89086	7.92536	
5	296.05557	26.00000	1.50839
6	-527.24081	1.04750	
7	478.04893	27.00000	1.50839
8	-948.34609	0.97572	
9	210.20717	24.00000	1.50839
10	107.85292	24.04713	
11	214.18600	26.00000	1.50839
12	-438.52759	1.10686	
13	-1434.49001	17.00000	1.50839
14	132.17373	18.76700	
15	-370.22109	12.90000	1.50839
16	137.36441	26.88549	
17	-131.18161	15.00000	1.50839

18	450.35044	53.03407	
19	1459.21001	35.00000	1.50839
20	-182.99101	14.91509	
21	-132.88561	22.80000	1.50839
22	-199.28914	2.79782	
23	-5536.72998	27.00000	1.50839
24	-310.74563	2.87255	
25	528.12523	28.00000	1.50839
26	-1200.55000	2.49780	
27	320.15215	30.00000	1.50839
28	-2820.19000	1.64701	
29	239.46093	31.00000	1.50839
30	-2425.69000	5.60527	
31	∞	21.00000	1.50839
32	148.13116	9.76890	
33	207.41773	17.00000	1.50839
34	155.42831	31.54706	
35	-218.29971	15.90000	1.50839
36	304.21175	56.74759	
37	-175.66635	18.00000	1.50839
38	-1130.86000	6.28784	
39	-485.73656	23.00000	1.50839
40	-216.43349	1.14438	
41	2806.14999	23.00000	1.50839
42	-316.00620	2.92283	
43	437.43410	38.00000	1.50839

44	-355.32964	11.43498	
45	-235.73758	27.00000	1.50839
46	-360.50104	1.10071	
47	410.57953	25.00000	1.50839
48	-3698.22000	4.83032	
49	178.15299	32.00000	1.50839
50	506.53177	3.29194	
51	137.46544	39.90000	1.50839
52	328.51597	9.82671	
53	544.32105	23.00000	1.50839
54	81.70638	7.04896	
55	92.81520	34.00000	1.50839
56	511.57718	2.00000	
57	482.15006	35.00000	1.50839
58	1631.30000		

(Table 4) Values corresponding to the Conditions in the Second Embodiment

(1) $f1/f3 = 1.50$

(2) $f2/f4 = 1.39$

(3) $f5/L = 0.0971$

(4) $f6/L = 0.158$

(5) $fn/f2 = 0.568$

(6) $I/L = 2.21$

(7) $f24/f23 = 1.01$

(8) $f22/f23 = 1.21$

(9) $D/L = 0.0858$

(10) $f4/L = -0.0621$

(11) $f2/L = -0.0861$

(12) $(r5p-r5n)/(r5p+r5n) = 0.202$

(13) $(r4F-r4R)/(r4F+r4R) = -0.731$

(14) $(r5R-r6F)/(r5R+r6F) = -0.0637$

(15) $d56/L = 0.00587$

(16) $d6/r6F = 1.08$

(17) $(r5F-r5R)/(r5F+r5R) = 0.739$

(18) $1/(\phi 21 \cdot L) = 0.719$

(19) $f21/L = 0.239$

(20) $f2F/f2R = 0.533$

(Table 5) Third Embodiment

d0 = 104.69561

B = 1/5

NA = 0.55

Bf = 29.13809

L = 1200

	r	d	n
1	1364.36000	23.00000	1.50839
2	-612.17411	20.81278	
3	699.63988	24.00000	1.50839
4	-301.81026	7.92536	
5	-248.00150	20.00000	1.50839
6	-614.52792	1.04750	
7	332.05244	27.00000	1.50839
8	-582.52759	0.97572	
9	232.12759	24.00000	1.50839
10	110.33434	27.04713	
11	230.79590	23.00000	1.50839
12	-359.85171	1.10686	
13	-1275.75999	17.00000	1.50839
14	127.98361	18.76700	
15	-569.83204	12.90000	1.50839
16	140.20359	26.88549	
17	-108.76770	15.00000	1.50839

18	593.61218	51.86789	
19	2324.85999	35.00000	1.50839
20	-163.53564	14.91509	
21	-121.26603	22.80000	1.50839
22	-192.12364	2.79782	
23	-4480.40997	27.00000	1.50839
24	-297.83388	2.87255	
25	445.50685	28.00000	1.50839
26	-877.28296	2.49780	
27	422.96766	27.00000	1.50839
28	-1570.03000	1.64701	
29	230.95785	31.00000	1.50839
30	3000.00000	8.60527	
31	1800.00000	21.00000	1.50839
32	138.38357	9.76890	
33	191.56081	17.00000	1.50839
34	157.70119	31.54706	
35	-217.22866	15.90000	1.50839
36	294.71194	56.69427	
37	-173.19975	18.00000	1.50839
38	-973.64548	6.28784	
39	-467.87775	23.00000	1.50839
40	-215.12034	1.14438	
41	2688.16000	23.00000	1.50839
42	-320.45010	2.92283	
43	441.22198	40.00000	1.50839

44	-347.09282	9.43498	
45	-239.46132	27.00000	1.50839
46	-386.98159	1.10071	
47	381.41679	28.00000	1.50839
48	-2576.25000	4.83032	
49	186.44642	29.00000	1.50839
50	570.80649	3.29194	
51	138.75412	39.90000	1.50839
52	316.26440	9.82671	
53	504.37073	23.00000	1.50839
54	80.26770	7.04896	
55	91.17058	71.00000	1.50839
56	1553.61000		

(Table 6) Values corresponding to the Conditions in the Third Embodiment

(1) $f1/f3 = 1.46$

(2) $f2/f4 = 1.27$

(3) $f5/L = 0.0977$

(4) $f6/L = 0.156$

(5) $fn/f2 = 0.591$

(6) $I/L = 2.93$

(7) $f24/f23 = 0.816$

(8) $f22/f23 = 1.04$

(9) $D/L = 0.0848$

(10) $f4/L = -0.0645$

(11) $f2/L = -0.0816$

(12) $(r5p-r5n)/(r5p+r5n) = 0.184$

(13) $(r4F-r4R)/(r4F+r4R) = -0.698$

(14) $(r5R-r6F)/(r5R+r6F) = -0.0636$

(15) $d56/L = 0.00587$

(16) $d6/r6F = 1.10$

(17) $(r5F-r5R)/(r5F+r5R) = 0.725$

(18) $1/(\phi 21 \cdot L) = 0.590$

(19) $f21/L = 0.234$

(20) $f2F/f2R = 0.611$

(Table 7) Fourth Embodiment

d0 = 104.71662

B = 1/5

NA = 0.55

Bf = 28.76320

L = 1200

	r	d	n
1	955.26796	23.00000	1.50839
2	-675.53148	20.81278	
3	788.04209	24.00000	1.50839
4	-320.77870	7.92536	
5	-261.99847	20.00000	1.50839
6	-613.40707	1.04750	
7	343.77433	27.00000	1.50839
8	-614.74297	0.97572	
9	220.40014	24.00000	1.50839
10	111.87626	27.04713	
11	230.00000	23.00000	1.50839
12	-410.00000	1.10686	
13	-2449.05000	17.00000	1.50839
14	118.87129	18.76700	
15	-632.77988	12.90000	1.50839
16	143.15226	26.88549	
17	-108.88557	15.00000	1.50839

18	595.22400	52.22565	
19	1526.21000	35.00000	1.50839
20	-168.52598	14.91509	
21	-120.87196	22.80000	1.50839
22	-188.10351	2.79782	
23	-3191.22000	27.00000	1.50839
24	-296.62706	2.87255	
25	697.45117	28.00000	1.50839
26	-669.27158	2.49780	
27	358.82454	27.00000	1.50839
28	-2986.21000	1.64701	
29	223.50971	31.00000	1.50839
30	-1510.16000	8.60527	
31	-3596.81000	21.00000	1.50839
32	141.11696	9.76890	
33	194.35300	17.00000	1.50839
34	157.66411	31.54706	
35	-209.96142	15.90000	1.50839
36	307.10883	56.68624	
37	-175.13115	18.00000	1.50839
38	-1162.95000	6.28784	
39	-505.38166	23.00000	1.50839
40	-213.39177	1.14438	
41	3114.45000	23.00000	1.50839
42	-339.03822	2.92283	
43	460.54759	40.00000	1.50839

44	-326.27369	9.43498	
45	-231.89968	27.00000	1.50839
46	-372.57441	1.10071	
47	390.03678	28.00000	1.50839
48	-1994.66000	4.83032	
49	182.18377	29.00000	1.50839
50	525.45378	3.29194	
51	138.67730	39.90000	1.50839
52	312.43609	9.82671	
53	511.48346	23.00000	1.50839
54	81.45867	7.04896	
55	93.64185	34.00000	1.50839
56	934.34560	2.00000	
57	826.70065	35.00000	1.50839
58	1680.21000	(Bf)	

(Table 8) Values corresponding to the Conditions in the Fourth Embodiment

(1) $f1/f3 = 1.55$

(2) $f2/f4 = 1.39$

(3) $f5/L = 0.0975$

(4) $f6/L = 0.158$

(5) $fn/f2 = 0.576$

(6) $I/L = 3.05$

(7) $f24/f23 = 0.787$

(8) $f22/f23 = 0.974$

(9) $D/L = 0.0851$

(10) $f4/L = -0.0606$

(11) $f2/L = -0.0843$

(12) $(r5p-r5n)/(r5p+r5n) = 0.169$

(13) $(r4F-r4R)/(r4F+r4R) = -0.738$

(14) $(r5R-r6F)/(r5R+r6F) = -0.0695$

(15) $d56/L = 0.00587$

(16) $d6/r6F = 1.07$

(17) $(r5F-r5R)/(r5F+r5R) = 0.725$

(18) $1/(\phi 21 \cdot L) = 0.672$

(19) $f21/L = 0.244$

(20) $f2F/f2R = 0.642$

(Table 9) Fifth Embodiment

d0 = 105.99385

B = 1/5

NA = 0.55

Bf = 28.96856

L = 1200

	r	d	n
1	723.32335	28.00000	1.50839
2	-571.27029	2.00000	
3	-8470.94995	20.00000	1.50839
4	324.13159	7.92536	
5	360.44110	28.00000	1.50839
6	-432.97069	1.04750	
7	397.04484	27.00000	1.50839
8	-825.96923	0.97572	
9	214.74004	31.00000	1.50839
10	110.51892	24.04713	
11	229.41181	26.00000	1.50839
12	-396.52854	1.10686	
13	-1014.34000	17.00000	1.50839
14	137.90605	18.76700	
15	-418.55207	12.90000	1.50839
16	138.89479	26.88549	
17	-133.71351	15.00000	1.50839

18	561.35918	52.53782	
19	1381.31000	35.00000	1.50839
20	-188.69074	14.91509	
21	-134.03345	22.80000	1.50839
22	-198.69180	2.79782	
23	-3029.37000	27.00000	1.50839
24	-333.96362	2.87255	
25	905.53484	28.00000	1.50839
26	-611.80005	2.49780	
27	254.70879	30.00000	1.50839
28	3936.53000	1.64701	
29	239.51669	31.00000	1.50839
30	-1238.94000	5.60527	
31	-2379.42001	21.00000	1.50839
32	150.43068	9.76890	
33	209.21387	17.00000	1.50839
34	149.67785	31.54706	
35	-199.55198	15.90000	1.50839
36	341.76300	57.70880	
37	-170.75300	18.00000	1.50839
38	-3700.60999	6.28784	
39	-1025.75000	23.00000	1.50839
40	-212.37919	1.14438	
41	-3009.97000	23.00000	1.50839
42	-312.33647	2.92283	
43	401.05778	37.00000	1.50839

44	-361.42967	12.43498	
45	-231.63315	27.00000	1.50839
46	-319.48896	1.10071	
47	355.64919	25.00000	1.50839
48	3678.53000	4.83032	
49	177.43364	32.00000	1.50839
50	553.83964	3.29194	
51	137.68248	39.90000	1.50839
52	330.86342	9.82671	
53	587.42747	23.00000	1.50839
54	81.23164	7.04896	
55	93.74477	71.00000	1.50839
56	1555.42999		

(Table 10) Values corresponding to the Conditions in the Fifth Embodiment

(1) $f1/f3 = 1.58$

(2) $f2/f4 = 1.63$

(3) $f5/L = 0.0923$

(4) $f6/L = 0.161$

(5) $fn/f2 = 0.554$

(6) $I/L = 2.27$

(7) $f24/f23 = 1.04$

(8) $f22/f23 = 1.17$

(9) $D/L = 0.0853$

(10) $f4/L = -0.0564$

(11) $f2/L = -0.0919$

(12) $(r5p-r5n)/(r5p+r5n) = 0.219$

(13) $(r4F-r4R)/(r4F+r4R) = -0.912$

(14) $(r5R-r6F)/(r5R+r6F) = -0.0715$

(15) $d56/L = 0.00587$

(16) $d6/r6F = 1.07$

(17) $(r5F-r5R)/(r5F+r5R) = 0.757$

(18) $1/(\phi 21 \cdot L) = 0.650$

(19) $f21/L = 0.242$

(20) $f2F/f2R = 0.541$

(Table 11) Sixth Embodiment

d0 = 105.91377

B = 1/5

NA = 0.55

Bf = 28.96856

L = 1200

	r	d	n
1	723.70616	28.00000	1.50839
2	-571.49375	1.98414	
3	-8427.42000	20.00000	1.50839
4	324.06902	8.06076	
5	360.49965	28.00000	1.50839
6	-432.97519	1.01484	
7	397.09644	27.00000	1.50839
8	-826.03537	0.88781	
9	214.74356	31.00000	1.50839
10	110.51666	24.03750	
11	229.41181	26.00000	1.50839
12	-396.60684	1.12963	
13	-1014.38000	17.00000	1.50839
14	137.92108	18.76756	
15	-418.59453	12.90000	1.50839
16	138.90550	26.88587	
17	-133.71351	15.00000	1.50839

18	561.20342	52.51989	
19	1381.31000	35.00000	1.50839
20	-188.68876	14.85490	
21	-134.03581	22.80000	1.50839
22	-198.68592	2.89585	
23	-3029.37000	27.00000	1.50839
24	-333.96362	2.88769	
25	905.64444	28.00000	1.50839
26	-611.80428	2.47699	
27	254.70879	30.00000	1.50839
28	3936.53000	1.61920	
29	239.51669	31.00000	1.50839
30	-1238.94000	5.60156	
31	-2379.42000	21.00000	1.50839
32	150.42879	9.73510	
33	209.20275	16.99160	1.50839
34	149.68297	31.54706	
35	-199.55198	15.90229	1.50839
36	341.76300	57.70389	
37	-170.75300	18.00000	1.50839
38	-3700.61000	6.28293	
39	-1025.75000	23.00000	1.50839
40	-212.37919	1.14438	
41	-3009.97000	23.00000	1.50839
42	-312.33647	2.89661	
43	401.05778	37.00000	1.50839

44	-361.42967	12.47918	
45	-231.65257	27.00000	1.50839
46	-319.51171	1.23912	
47	355.64919	25.00000	1.50839
48	3678.53000	4.82925	
49	177.43453	32.00000	1.50839
50	553.98339	3.26768	
51	137.68248	39.90000	1.50839
52	330.86342	9.82671	
53	587.42747	23.00000	1.50839
54	81.23164	7.04896	
55	93.74477	71.00000	1.50839
56	1555.43000	(Bf)	

(Table 12) Values corresponding to the Conditions in the Sixth Embodiment

(1) $f1/f3 = 1.58$

(2) $f2/f4 = 1.63$

(3) $f5/L = 0.0924$

(4) $f6/L = 0.161$

(5) $fn/f2 = 0.554$

(6) $I/L = 2.25$

(7) $f24/f23 = 1.04$

(8) $f22/f23 = 1.17$

(9) $D/L = 0.0853$

(10) $f4/L = -0.0564$

(11) $f2/L = -0.0919$

(12) $(r5p-r5n)/(r5p+r5n) = 0.218$

(13) $(r4F-r4R)/(r4F+r4R) = -0.911$

(14) $(r5R-r6F)/(r5R+r6F) = -0.0715$

(15) $d56/L = 0.00587$

(16) $d6/r6F = 1.07$

(17) $(r5F-r5R)/(r5F+r5R) = 0.757$

(18) $1/(\phi 21 \cdot L) = 0.650$

(19) $f21/L = 0.242$

(20) $f2F/f2R = 0.541$

In the above-described first embodiment, $1/|\Phi L| = 0.149$ for the object-side lens surface of the positive lens L_{61}, thus satisfying the condition (21). In the second embodiment, $1/|\Phi L| = 0.152$ for the object-side lens surface of the positive lens L_{61} and $1/|\Phi L| = 0.709$ for the object-side lens surface of the positive lens L_{62}, thus satisfying the condition (21). In the third embodiment, $1/|\Phi L| = 0.149$ for the object-side lens surface of the positive lens L_{61}, thus satisfying the condition (21). In the fourth embodiment, $1/|\Phi L| = 0.153$ for the object-side lens surface of the positive lens L_{61} and $1/|\Phi L| = 1.36$ for the object-side lens surface of the positive lens L_{62}, thus satisfying the condition (21). In the fifth embodiment, $1/|\Phi L| = 0.153$ for the object-side lens surface of the positive lens L_{61}, thus satisfying the condition (21). In the sixth embodiment, $1/|\Phi L| = 0.154$ for the object-side lens surface of the positive lens L_{61}, thus satisfying the condition (21). Therefore, the sixth lens group G_6 in each embodiment is composed of three or less lenses having the lens surface(s) satisfying the condition (21).

From the above values of specifications for the respective embodiments, it is understood that the telecentricity is achieved on the object side (on the reticle side) and on the image side (on the wafer side) while maintaining a relatively wide exposure area and a large numerical aperture in each embodiment.

Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, and Fig. 14 show aberration diagrams of various aberrations in the first to the sixth embodiments according to the present invention.

Here, in each aberration diagram, NA represents the numerical aperture of the projection optical system and Y the image height. In each aberration diagram of astigmatism, the dotted line represents a meridional image surface (meridional image surface) and the solid line a sagittal image surface (sagittal image surface).

From comparison of the aberration diagrams, it is seen that the various aberrations are corrected in a good balance in each embodiment, particularly the distortion is corrected very well over the entire image up to a nearly zero state and the high-resolving-power projection optical system is achieved with a large numerical aperture.

Although the above embodiments showed the examples where the excimer laser for supplying the light of 248.4 nm was used as a light source, it is needless to mention that, without a need to be limited to the examples, the present invention can be applied to systems using extreme ultraviolet light sources such as an excimer laser for supplying the light of 193 nm, mercury arc lamps for supplying the light of the g-line (436 nm) or the i-line (365 nm), or light sources for supplying the light in the ultraviolet region other than those.

In the embodiments neither of the lenses constituting the projection optical system is a compound lens, and either of them is made of a single optical material, i.e., of quartz (SiO_2). Here, a cost reduction can be achieved because a single optical material forms each lens in the above embodiments. However, if the exposure light has a certain half width, a chromatic aberration can be corrected by a combination of quartz (SiO_2) and fluorite (CaF_2) or by a combination of other optical materials. Further, if the exposure light source supplies the exposure light in a wide band, the chromatic aberration can be corrected by a combination of plural types of optical materials.

As described above, the exposure apparatus relating to the present invention has achieved the projection optical systems which are bitelecentric optical systems with a relatively wide exposure area kept and which are high-resolving-power projection optical systems in which the various aberrations are corrected in a good balance and which have a large numerical aperture. Particularly, the distortion is corrected very well in the projection optical systems of the present invention. Accordingly, the present invention can enjoy an extreme reduction of image stress, because the distortion is also corrected very well in addition to the achievement of the bitelecentricity.

From the invention thus described, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

The basic Japanese Application No. 6-311050 (311050/1994) filed on December 14, 1994 is hereby incorporated by reference.

Claims

1. A projection optical system located between a first and second objects, for projecting an image of the first object onto the second object, said projection optical system having:

   a first lens group with positive refracting power, said first lens group being placed between the first and second objects;

   a second lens group with negative refracting power, said second lens group being placed between said first lens group and the second object;

   a third lens group with positive refracting power, said third lens group being placed between said second lens group and the second object;

   a fourth lens group with negative refracting power, said fourth lens group being placed between said third lens group and the second object;

   a fifth lens group with positive refracting power, said fifth lens group being placed between said fourth lens group and the second object; and

   a sixth lens group with positive refracting power, said six lens group being placed between said fifth lens group and the second object.

2. A projection optical system according to claim 1, wherein said first lens group includes at least two positive lenses, said third lens group includes at least three positive lenses, said fourth lens group includes at least three negative lenses, said fifth lens group includes at least five positive lenses and at least one negative lens, and said sixth lens group includes at least one positive lens.

3. A projection optical system according to claim 1, wherein said second lens group comprises a front lens placed as closest to the first object and having negative refracting power with a concave surface to the second object, a rear lens placed as closest to the second object and having negative refracting power with a concave surface to the first

object, and an intermediate lens group placed between said front and rear lenses in said second lens group, and

wherein said intermediate lens group has a first lens with positive refracting power, a second lens with negative refracting power, a third lens with negative refracting power, and a fourth lens with negative refracting power in the named order from the side of the first object.

4. A projection optical system according to claim 3, wherein the first lens with positive refracting power in said intermediate lens group in said second lens group has a lens shape with a convex surface to the second object.

5. A projection optical system according to claim 2, wherein said fourth lens group comprises a front lens placed as closest to the first object and having negative refracting power with a concave surface to the second object, a rear lens placed as closest to the second object and having negative refracting power with a concave surface to the first object, and at least one negative lens placed between said front lens in said fourth lens group and said rear lens in said fourth lens group.

6. A projection optical system according to claim 1, wherein said fifth lens group comprises a negative meniscus lens, and a positive lens placed as adjacent to a concave surface of said negative meniscus lens and having a convex surface opposed to the concave surface of said negative meniscus lens.

7. A projection optical system according to claim 6, wherein said negative meniscus lens and said positive lens adjacent to the concave surface of said negative meniscus lens are placed between at least one positive lens in said fifth lens group and at least one positive lens in said fifth lens group.

8. A projection optical system according to claim 1, wherein said fifth lens group comprises a negative lens placed as closest to the second object and having a concave surface opposed to the second object.

9. A projection optical system according to claim 8, wherein said sixth lens group comprises a lens placed as closest to the first object and having a convex surface opposed to the first object.

10. A projection optical system located between a first and second object, for projecting an image of the first object onto the second object, said projection optical system having a first lens group with positive refracting power, a second lens group, a third lens group with positive refracting power, a fourth lens group with negative refracting power, a fifth lens group with positive refracting power, and a sixth lens group with positive refracting power in the named order from the side of the first object,

wherein said second lens group comprises a front lens placed as closest to the first object and having negative refracting power with a concave surface to the second object, a rear lens placed as closest to the second object and having negative refracting power with a concave surface to the first object, and an intermediate lens group placed between said front and rear lenses in said second lens group,

wherein said intermediate lens group has a first lens with positive refracting power, a second lens with negative refracting power, a third lens with negative refracting power, and a fourth lens with negative refracting power in the named order from the side of the first object, and

wherein the following conditions are satisfied when a focal length of said first lens group is f_1, a focal length of said second lens group is f_2, a focal length of said third lens group is f_3, a focal length of said fourth lens group is f_4, a focal length of said fifth lens group is f_5, a focal length of said sixth lens group is f_6, an overall focal length of said second lens to said fourth lens in said intermediate lens group in said second lens group is f_n, and a distance from the first object to the second object is L:

$$0.1 < f_1/f_3 < 17$$

$$0.1 < f_2/f_4 < 14$$

$$0.01 < f_5/L < 0.9$$

$$0.02 < f_6/L < 1.6$$

$$0.01 < f_n/f_2 < 2.0.$$

11. A projection optical system according to claim 10, wherein the following condition is satisfied when an axial distance from the first object to a first-object-side focal point of the whole of said projection optical system is l and the distance from the first object to the second object is L:

$$1.0 < l/L.$$

12. A projection optical system according to claim 10, wherein said first lens group includes at least two positive lenses, said third lens group includes at least three positive lenses, said fourth lens group includes at least three negative lenses, said fifth lens group includes at least five positive lenses and at least one negative lens, and said sixth lens group includes at least one positive lens.

13. A projection optical system according to claims 10, wherein said intermediate lens group in said second lens group has negative refracting power.

14. A projection optical system according to claims 10, wherein the following condition is satisfied when the focal length of said second lens group is f_2 and the distance from the first object to the second object is L:

$$-0.8 < f_2/L < -0.050.$$

15. A projection optical system according to claims 10, wherein the following condition is satisfied when a focal length of said front lens placed as closest to the first object in said second lens group and having negative refracting power with a concave surface to the second object is f_{2F} and a focal length of said rear lens placed as closest to the second object in said second lens group and having negative refracting power with a concave surface to the first object is f_{2R}:

$$0 \leq f_{2F}/f_{2R} < 18.$$

16. A projection optical system according to claim 10, wherein the following condition is satisfied when a focal length of said third lens with negative refracting power in said second lens group is f_{23} and a focal length of said fourth lens with negative refracting power in said intermediate lens group in said second lens group is f_{24}:

$$0.07 < f_{24}/f_{23} < 7.$$

17. A projection optical system according to claim 10, wherein the following condition is satisfied when a focal length of said second lens with negative refracting power in said intermediate lens group in said second lens group is f_{22} and a focal length of said third lens with negative refracting power in said intermediate lens group in said second lens group is f_{23}:

$$0.1 < f_{22}/f_{23} < 10.$$

18. A projection optical system according to claim 10, wherein the following condition is satisfied when an axial distance from a second-object-side lens surface of said fourth lens with negative refracting power in said intermediate lens group in said second lens group to a first-object-side lens surface of said rear lens in said second lens group is D and the distance from the first object to the second object is L:

$$0.05 < D/L < 0.4.$$

19. A projection optical system according to claim 10, wherein said first lens with positive refracting power in said intermediate lens group in said second lens group has a lens shape with a convex surface to the second object, and wherein the following condition is satisfied when the refracting power of a second-object-side lens surface of said first lens with positive refracting power in said intermediate lens group in said second lens group is Φ_{21} and the distance from the first object to the second object is L:

$$0.54 < 1/(\Phi_{21} \cdot L) < 10.$$

20. A projection optical system according to claim 10, wherein the following condition is satisfied when a focal length of said first lens with positive refracting power in said intermediate lens group in said second lens group is f_{21} and the distance from the first object to the second object is L:

$$0.230 < f_{21}/L < 0.40.$$

21. A projection optical system according to claim 10, wherein the following condition is satisfied when the focal length of said fourth lens group is f_4 and the distance from said the first object to the second object is L:

$$-0.098 < f_4/L < -0.005.$$

22. A projection optical system according to claim 10, wherein said fourth lens group comprises a front lens placed as closest to the first object and having negative refracting power with a concave surface to the second object, a rear lens placed as closest to the second object and having negative refracting power with a concave surface to the first object, and at least one negative lens placed between said front lens in said fourth lens group and said rear lens in said fourth lens group, and

wherein the following condition is satisfied when a radius of curvature on the first object side in said rear lens placed as closest to the second object in said fourth lens group is r_{4F} and a radius of curvature on the second object side in said rear lens placed as closest to the second object in said fourth lens group is r_{4R}:

$$-1.00 \leq (r_{4F} - r_{4R})/(r_{4F} + r_{4R}) < 0.$$

23. A projection optical system according to claim 10, wherein said fifth lens group comprises a negative meniscus lens, and a positive lens placed as adjacent to a concave surface of said negative meniscus lens and having a convex surface opposed to the concave surface of said negative meniscus lens, and

wherein the following condition is satisfied when a radius of curvature of the concave surface of said negative meniscus lens in said fifth lens group is r_{5n} and a radius of curvature of the convex surface opposed to the concave surface of said negative meniscus lens in said positive lens placed adjacent to the concave surface of said negative meniscus lens in said fifth lens group is r_{5p} :

$$0 < (r_{5p} - r_{5n})/(r_{5p} + r_{5n}) < 1.$$

24. A projection optical system according to claim 23, wherein said negative meniscus lens and said positive lens adjacent to the concave surface of said negative meniscus lens are placed between at least one positive lens in said fifth lens group and at least one positive lens in said fifth lens group.

25. A projection optical system according to claim 10, wherein said fifth lens group comprises a negative lens placed as closest to the second object and having a concave surface opposed to the second object, and

wherein the following condition is satisfied when a radius of curvature on the first object side in said negative lens closest to the second object in said fifth lens group is r_{5F} and a radius of curvature on the second object side in said negative lens closest to the second object in said fifth lens group is r_{5R}:

$$0.30 < (r_{5F} - r_{5R})/(r_{5F} + r_{5R}) < 1.28.$$

26. A projection optical system according to claim 10, wherein said fifth lens group comprises a negative lens placed as closest to the second object and having a concave surface opposed to the second object and said sixth lens group comprises a lens placed as closest to the first object and having a convex surface opposed to the first object, and

wherein the following condition is satisfied when a radius of curvature on the second object side, of said negative lens placed as closest to the second object in said fifth lens group is r_{5R} and a radius of curvature on the first object side, of said lens placed as closest to the first object in said sixth lens group is r_{6F}:

$$-0.90 < (r_{5R} - r_{6F})/(r_{5R} + r_{6F}) < -0.001.$$

27. A projection optical system according to claim 10, wherein the following condition is satisfied when a lens group separation between said fifth lens group and said sixth lens group is d_{56} and the distance from the first object to the second object is L:

$$d_{56}/L < 0.017.$$

28. A projection optical system according to claim 10, wherein the following condition is satisfied when a radius of curvature of a lens surface closest to the first object in said sixth lens group is r_{6F} and an axial distance from the lens surface closest to the first object in said sixth lens group to the second object is d_6:

$$0.50 < d_6/r_{6F} < 1.50.$$

29. A projection optical system according to claim 10, wherein said sixth lens group comprises three or less lenses having at least one surface satisfying the following condition:

$1/|\Phi L| < 20.$

where Φ: refracting power of the lens surface;
L: object-image distance from the first object to the second object.

30. A projection optical system according to claims 10, wherein a magnification of said projection optical system is 5:1.

31. An exposure apparatus comprising:
a stage allowing a photosensitive substrate to be held on a main surface thereof;
an illumination optical system for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern on a mask onto the substrate; and
a projecting optical system for projecting an image of the mask, on the substrate surface, said projecting optical system having:
a first lens group with positive refracting power, said first lens group being placed betwen the mask and the main surface of said stage;
a second lens group with negative refracting power, said second lens group being placed between said first lens group and the main surface of said stage;
a third lens group with positive refracting power, said third lens group being placed between said second lens group and the main surface of said stage;
a fourth lens group with negative refracting power, said fourth lens group being placed between said third lens group and the main surface of said stage;
a fifth lens group with positive refracting power, said fifth lens group being placed between said fourth lens group and the main surface of said stage; and
a sixth lens group with positive refracting power, said sixth lens group being placed between said fifth lens group and the main surface of said stage.

32. An exposure apparatus according to claim 31, wherein said second lens group comprises a front lens placed as closest to the first object and having negative refracting power with a concave surface to the second object, a rear lens placed as closest to the second object and having negative refracting power with a concave surface to the first object, and an intermediate lens group placed between said front and rear lenses in said second lens group,
wherein said intermediate lens group has a first lens with positive refracting power, a second lens with negative refracting power, a third lens with negative refracting power, and a fourth lens with negative refracting power in the named order from the side of the first object, and
wherein the following conditions are satisfied when a focal length of said first lens group is f_1, a focal length of said second lens group is f_2, a focal length of said third lens group is f_3, a focal length of said fourth lens group is f_4, a focal length of said fifth lens group is f_5, a focal length of said sixth lens group is f_6, an overall focal length of said second lens to said fourth lens in said intermediate lens group in said second lens group is f_n, and a distance from the first object to the second object is L:

$$0.1 < f_1/f_3 < 17$$

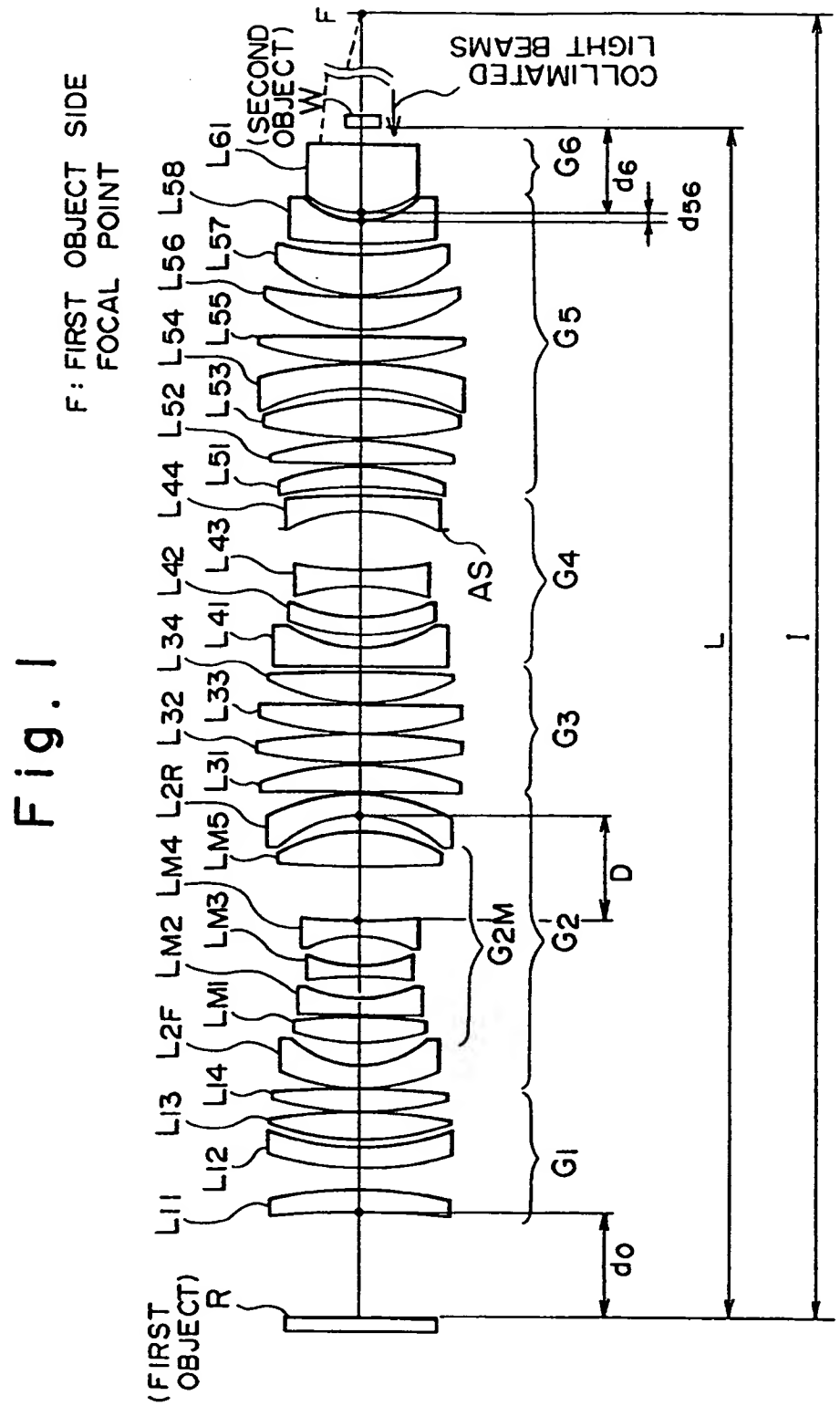
$$0.1 < f_2/f_4 < 14$$

$$0.01 < f_5/L < 0.9$$

$$0.02 < f_6/L < 1.6$$

$$0.01 < f_n/f_2 < 2.0.$$

Fig. 1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COLLIMATED LIGHT BEAMS
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LM4
LM3
LM2
LM1
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L13
L12
L11
(FIRST OBJECT) R
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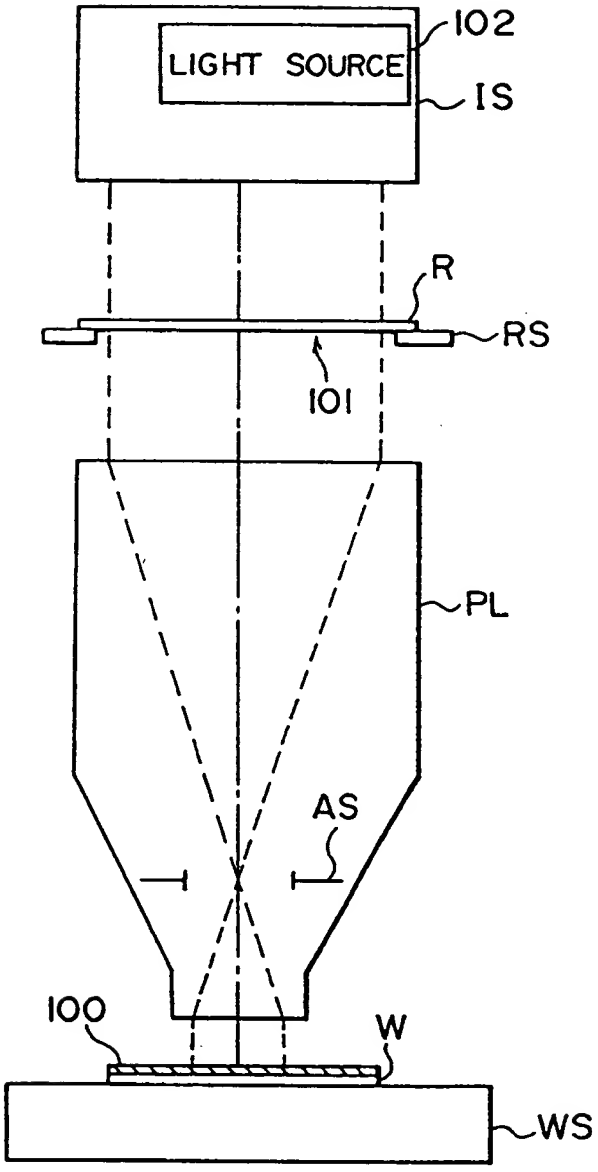
d0
L
l

Fig. 2



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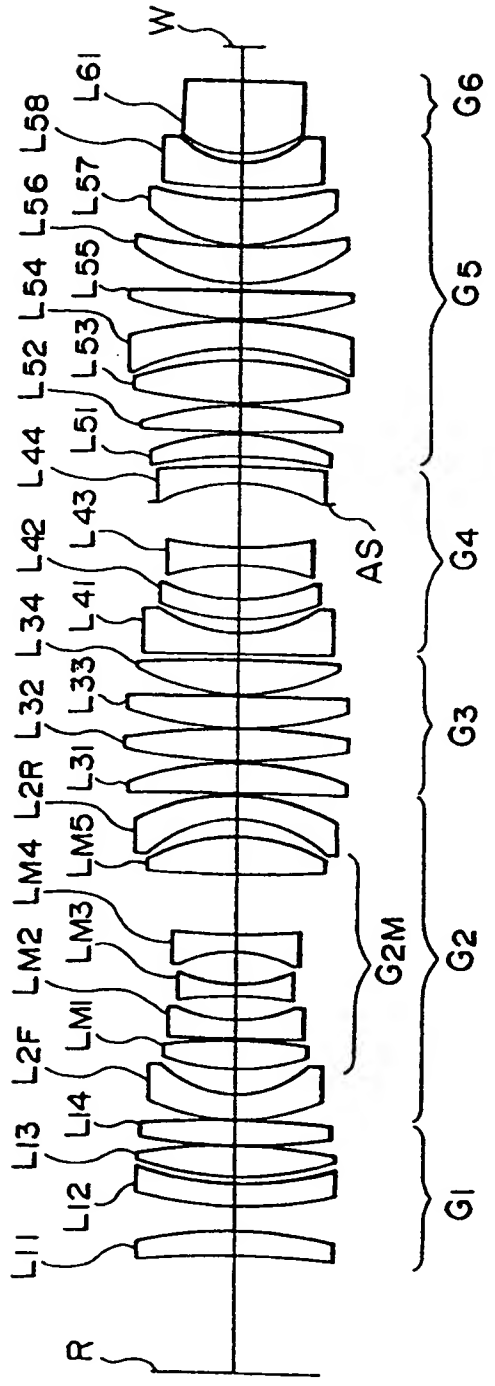
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Fig. 4

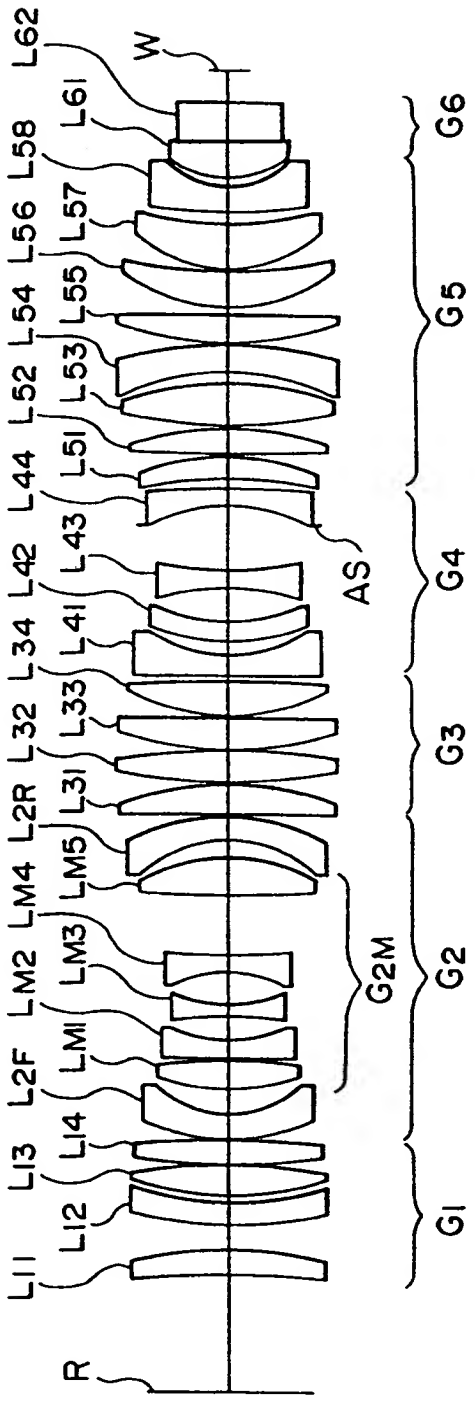
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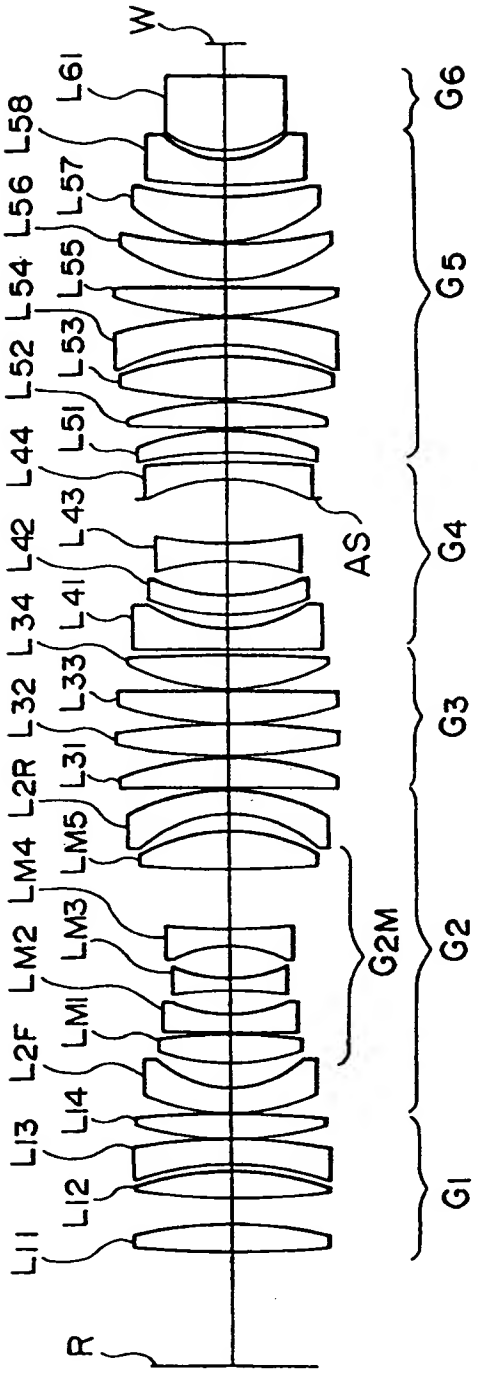
Fig. 5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G1

Fig. 6

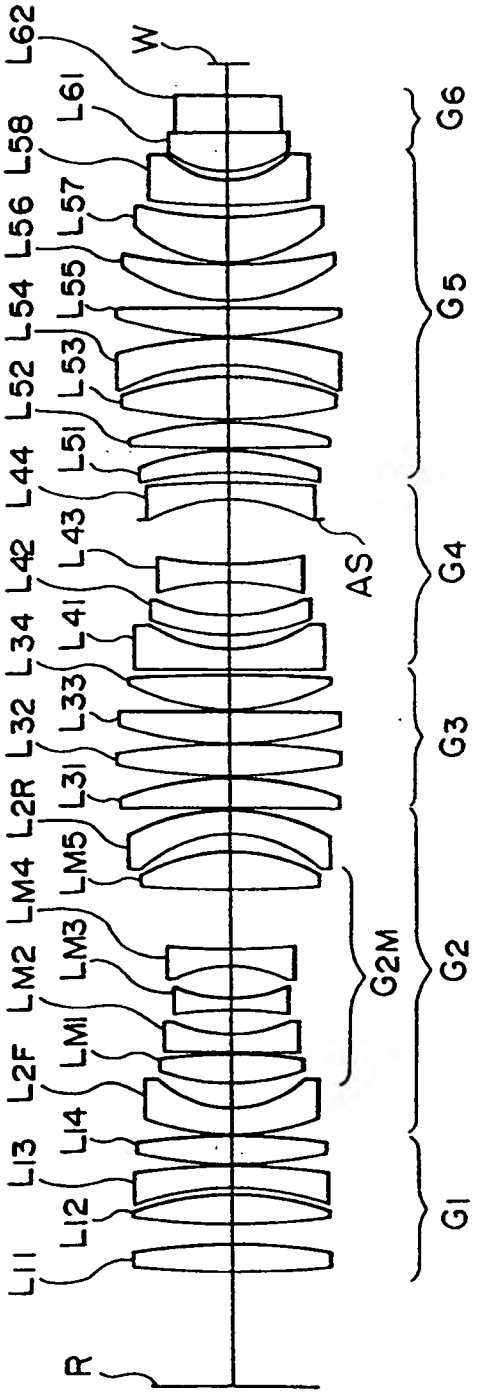
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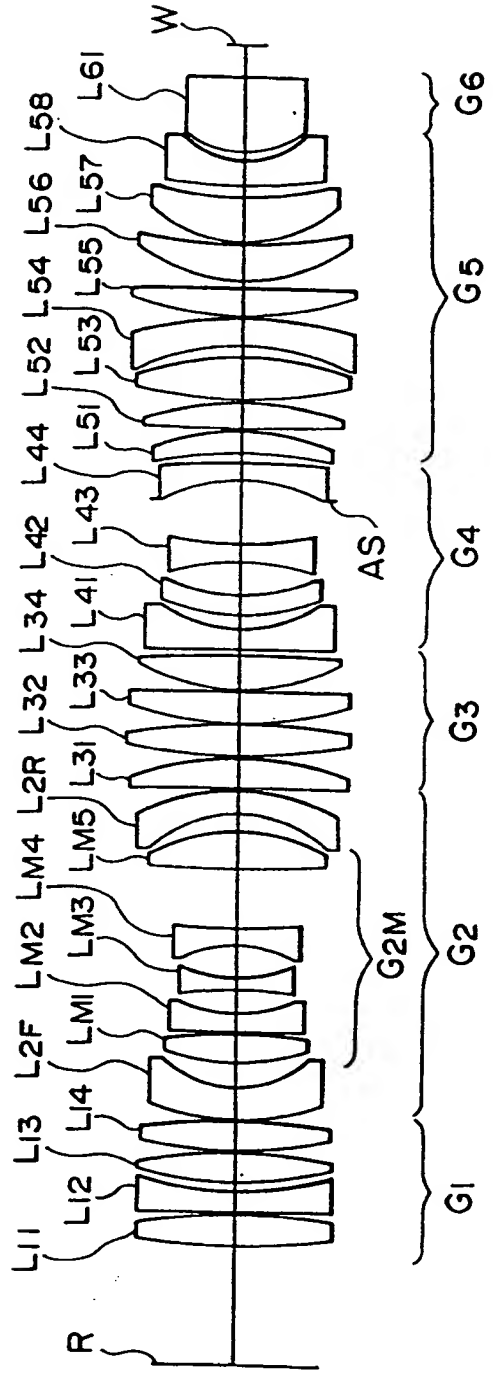
Fig. 7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G1

Fig. 8

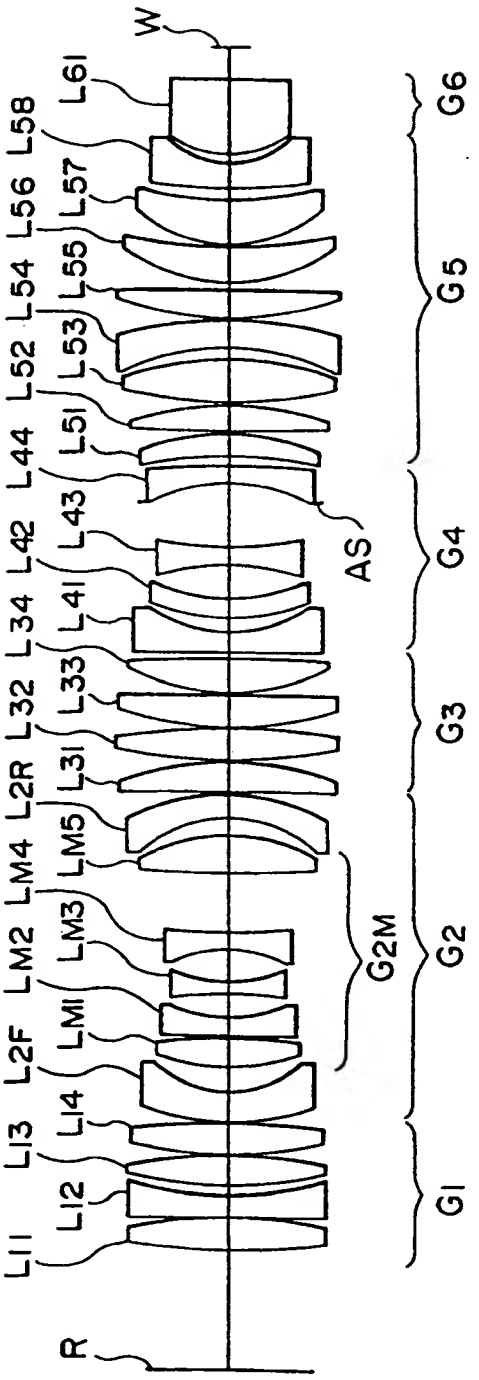
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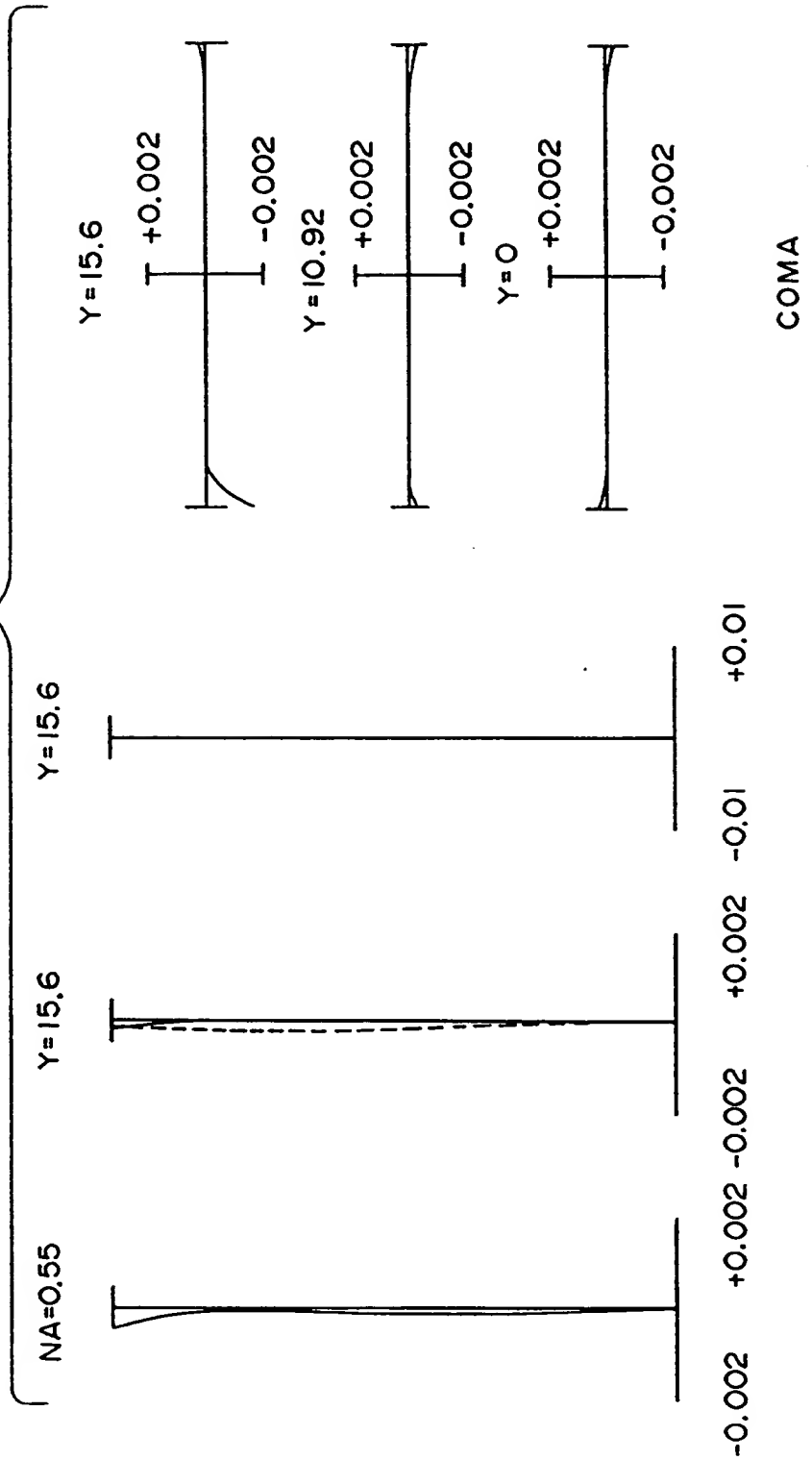
Fig. 9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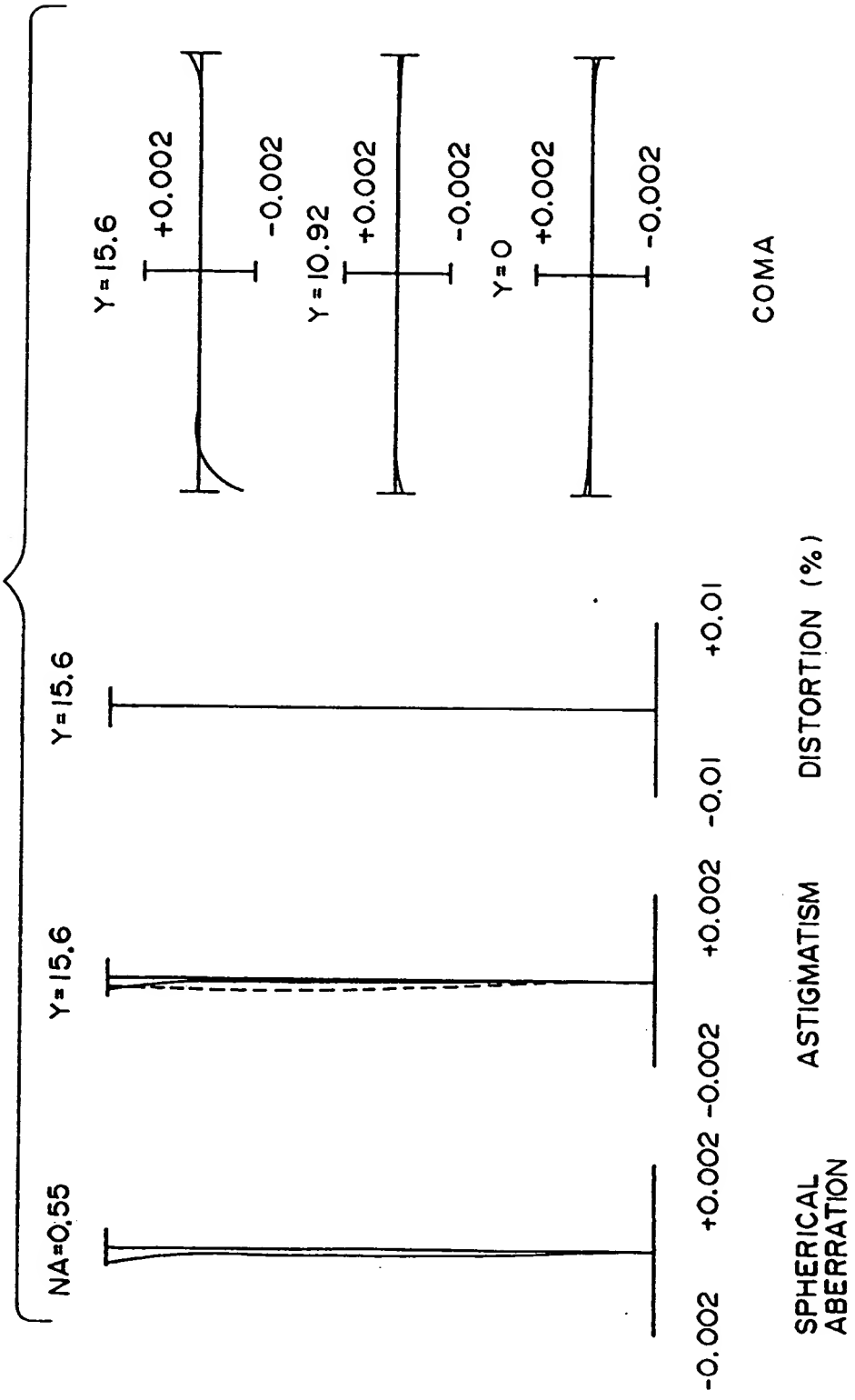
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
COMA

Fig. 10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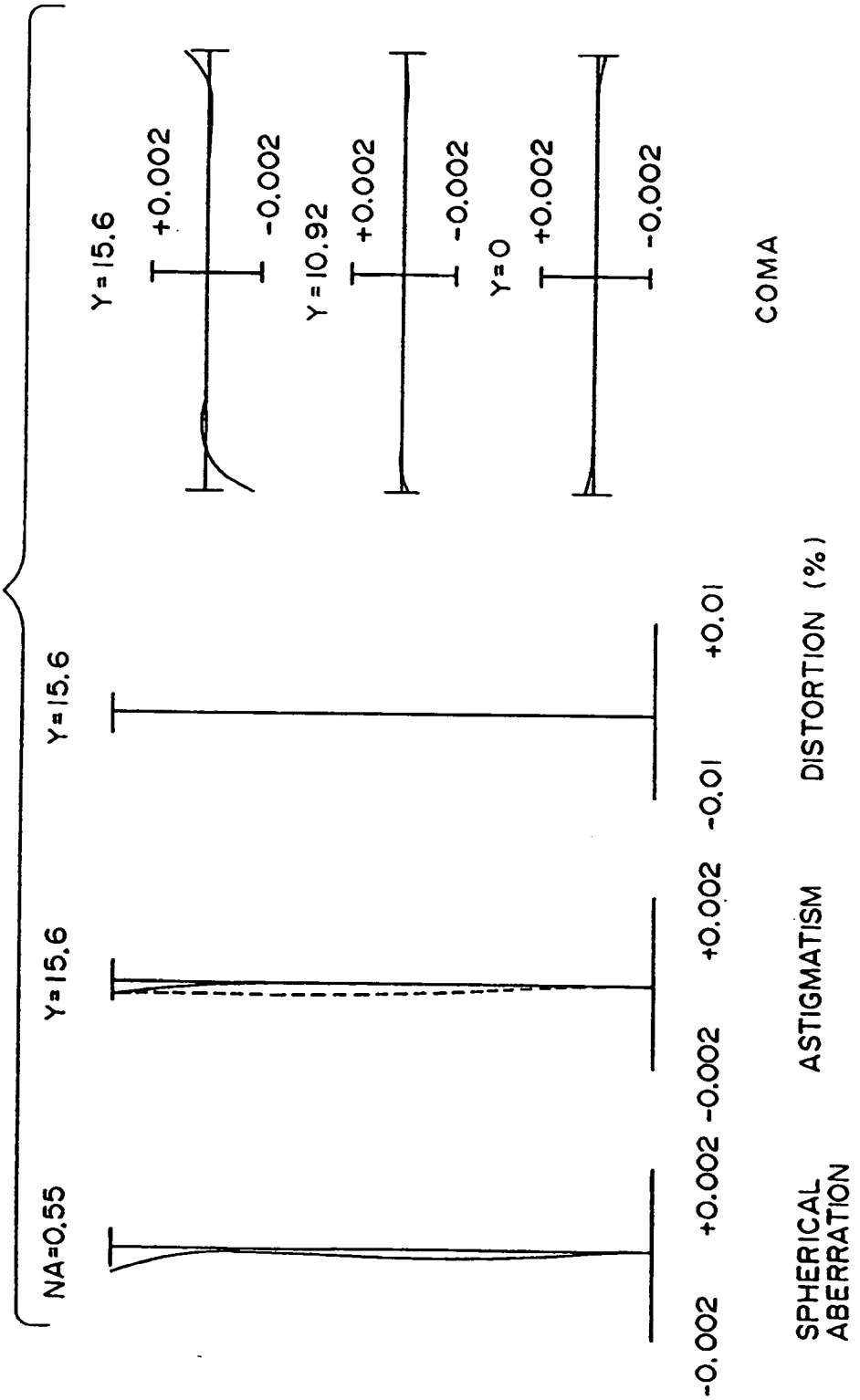
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
COMA

Fig. 11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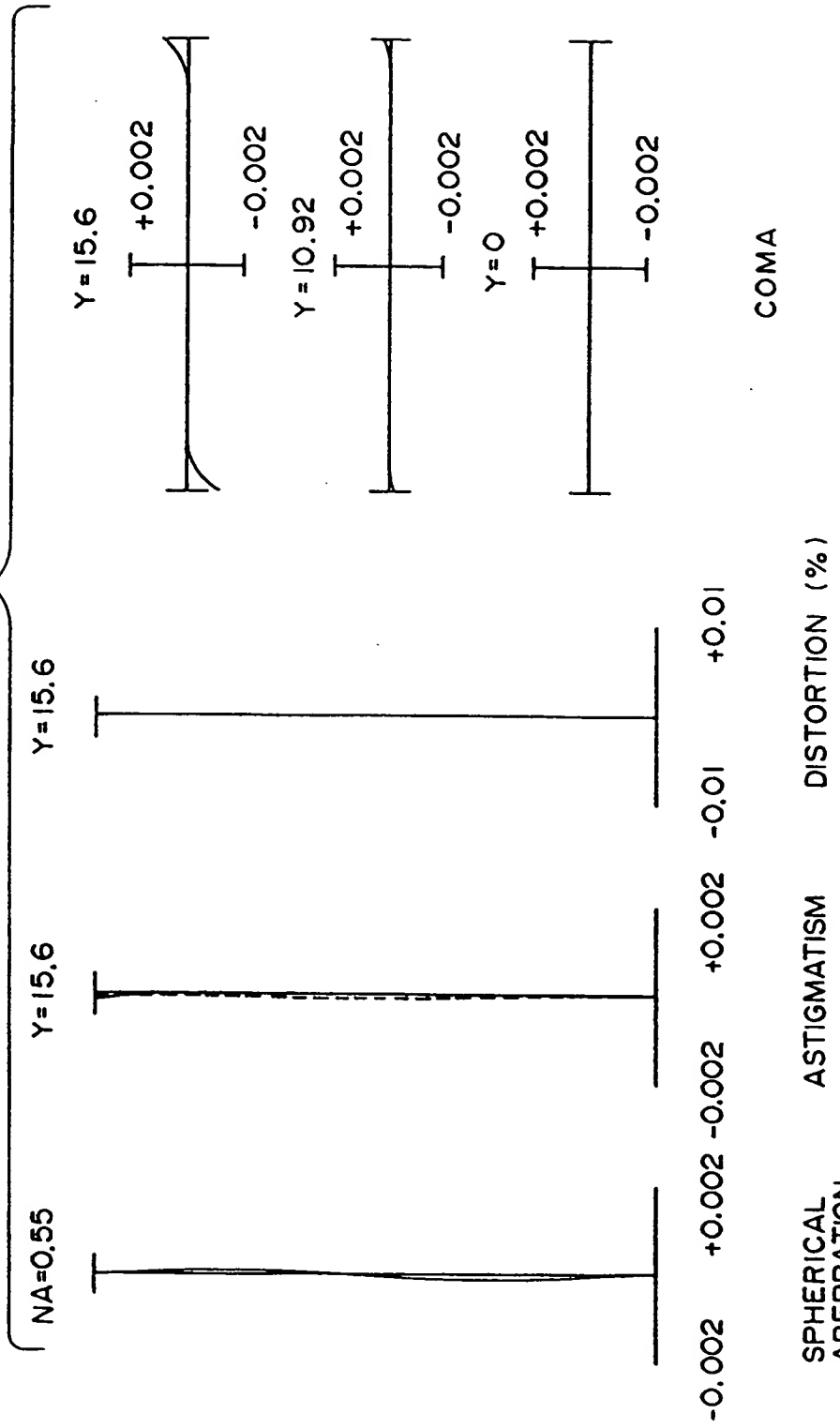
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
COMA

Fig. 12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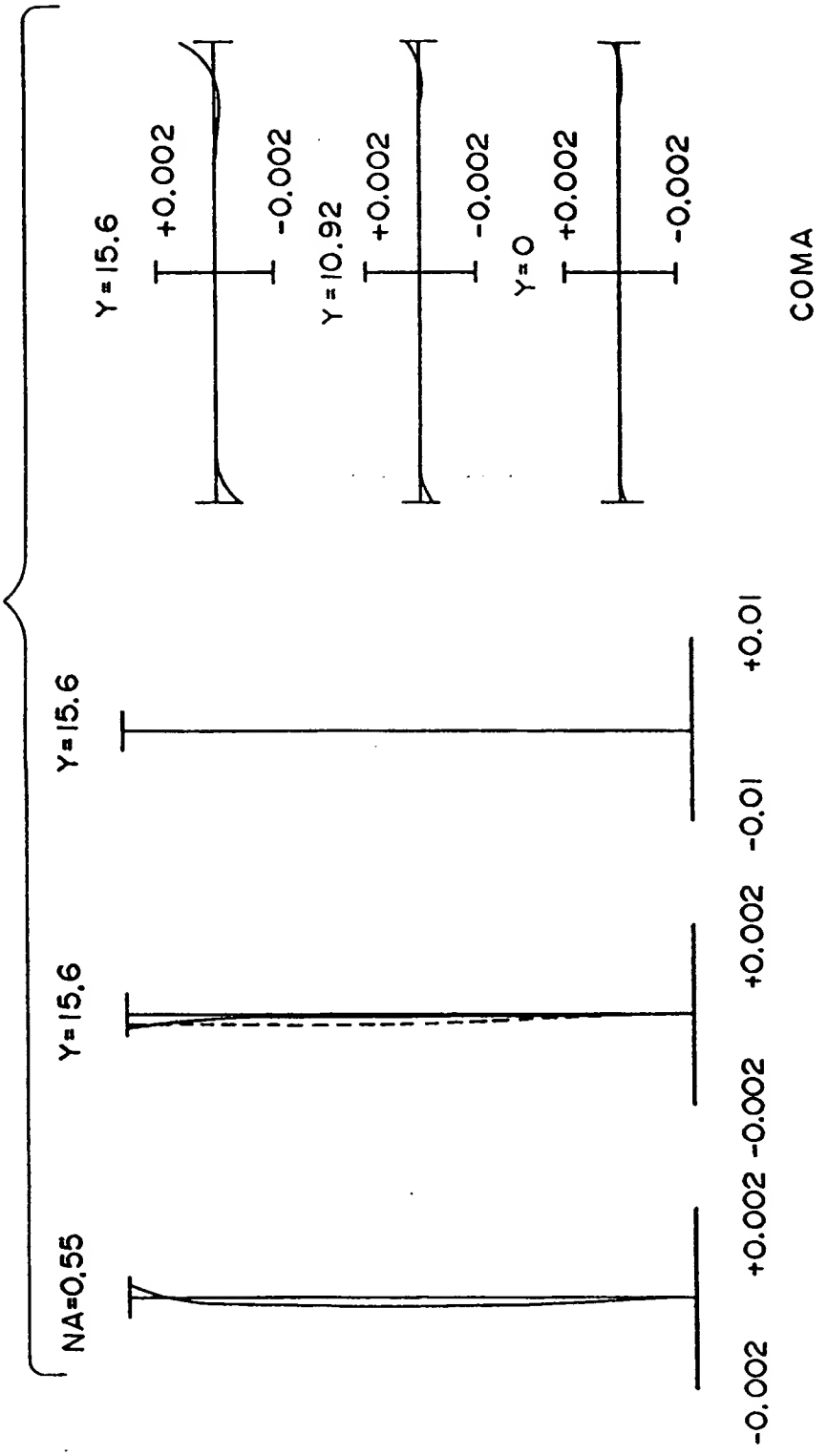
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
COMA

Fig. 13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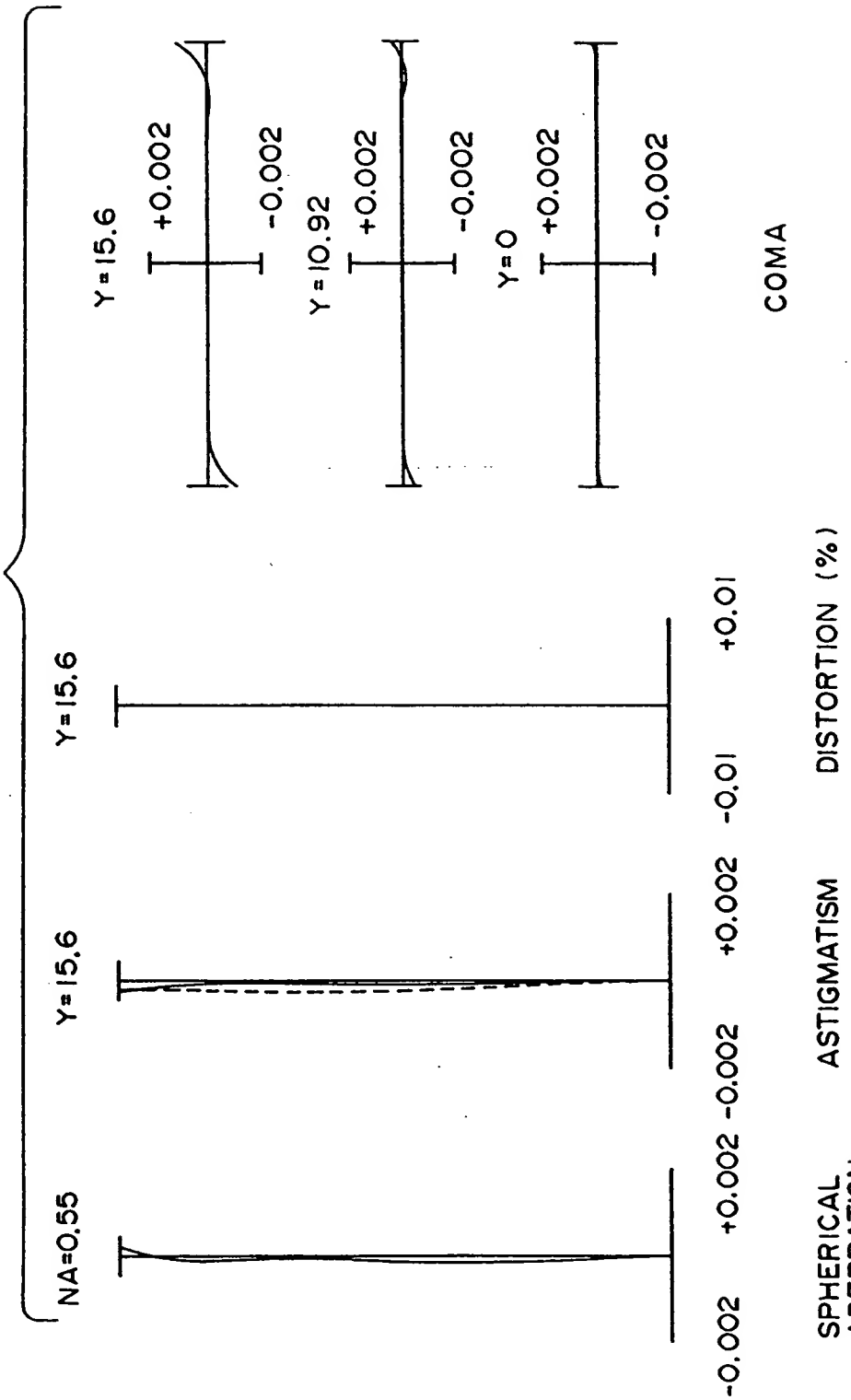
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
COMA

Fig. 14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SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION (%)
COMA

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 10 1619

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US-A-5 159 496 (KATAOKA) * the whole document *	1,10,31	G02B13/24 G02B9/62 G02B13/14
A	US-A-3 737 215 (DE JAGER) * the whole document *	1,10,31	G03F7/20
A	US-A-4 080 048 (KIMURA) * the whole document *	1,10,31	
A	WO-A-93 04391 (EASTMAN KODAK) * the whole document *	1,10,31	
A	US-A-3 955 883 (SUGIYAMA) * the whole document *	1,10,31	
A	PATENT ABSTRACTS OF JAPAN vol. 7, no. 73 (P-186) 25 March 1983 & JP-A-58 004 112 (OLYMPUS) * abstract; figure *	1,10,31	
D,A	US-A-5 260 832 (TOGINO ET AL) * the whole document *	1,10,31	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G02B G03F
D,A	PATENT ABSTRACTS OF JAPAN vol. 17, no. 586 (P-1633) 26 October 1993 & JP-A-05 173 065 (OLYMPUS) 13 July 1993 * abstract; figure *	1,10,31	
D,A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 366 (P-765) 30 September 1988 & JP-A-63 118 115 (SIGMA) 23 May 1988 * abstract; figure *	1,10,31	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 April 1995	Ward, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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& : member of the same patent family, corresponding document

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